

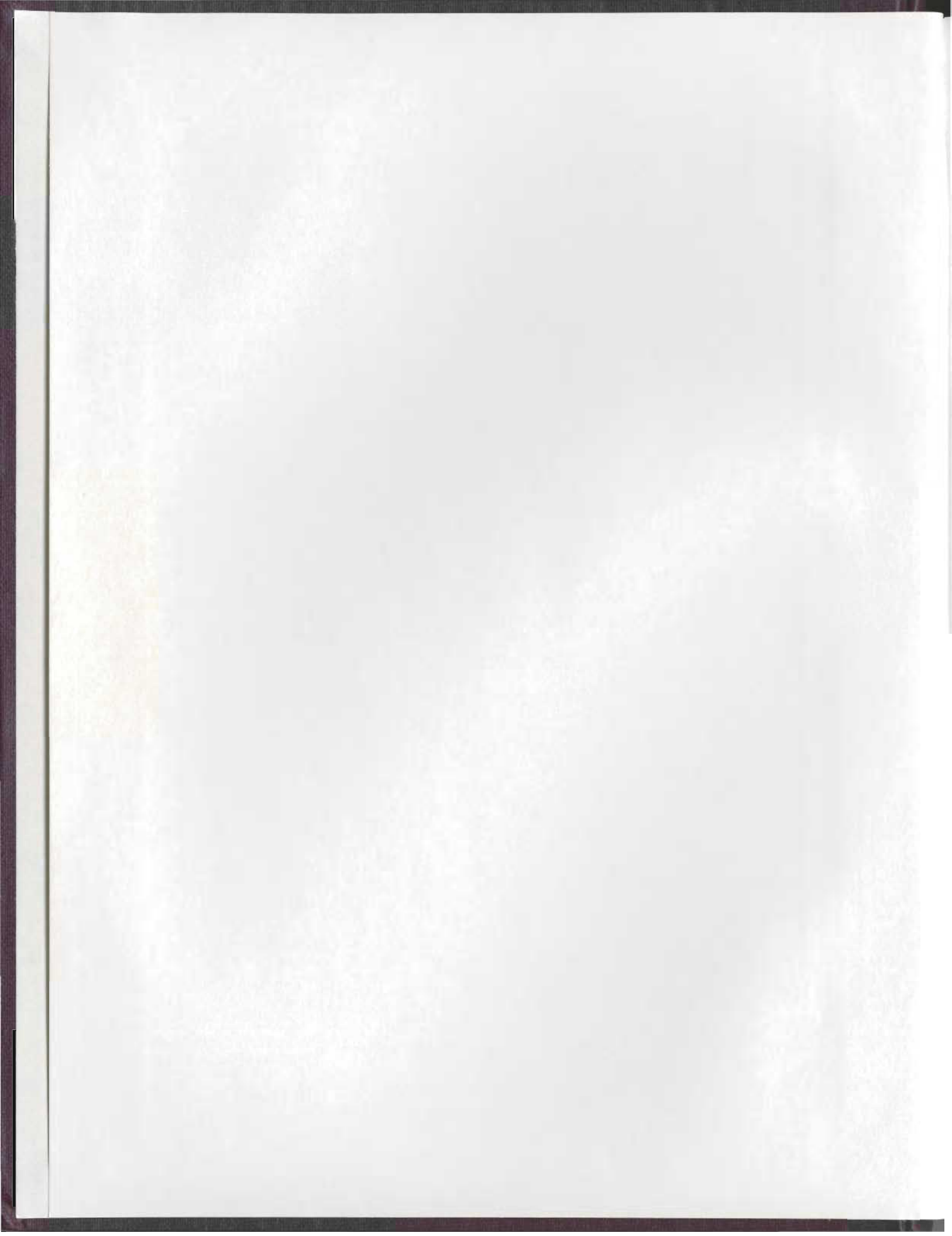
ACRITARCH BIOSTRATIGRAPHY AND TAXONOMY OF THE  
WINTERHOUSE FORMATION (UPPER ORDOVICIAN),  
PORT AU PORT PENINSULA, NEWFOUNDLAND

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**ACRITARCH BIOSTRATIGRAPHY AND TAXONOMY OF THE  
WINTERHOUSE FORMATION (UPPER ORDOVICIAN),  
PORT AU PORT PENINSULA, NEWFOUNDLAND.**

by

**Helen Gillespie**

**A thesis submitted to the  
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in partial fulfilment of the  
requirements for degree of  
Master of Science**

**Department of Earth Sciences  
Memorial University of Newfoundland**

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## ABSTRACT

The Upper Ordovician Winterhouse Formation (Long Point Group) is exposed only along the northwestern coast of Long Point on the Port au Port Peninsula, southwest Newfoundland. Detailed acritarch study of this formation has identified 74 palynomorph species assigned to 31 genera. One new combination, *Ammonidium parvipinnatum* (Uutela and Tynni), is proposed here. Fossils are extremely well preserved. An average Acritarch Alteration Index of  $1.6 \pm 0.3$  in transmitted light corresponding with clear and colourless to pale yellow and white to bright yellow in fluorescence, indicates that these acritarchs have undergone very little thermal maturation. These rocks sit at or above the oil window. Co-occurrence of *Villosacapsula setosapellicula*, *Multiplicisphaeridium irregulare*, *Ordoviciidium heteromorphicum*, *Petaloferidium stigii*, *Cheleutochroa diaphorasa*, *Dicommopalla macadamii*, *Actinotodissus crassus*, *Poikilofusa spinata*, and *Excultibrachium concinnum* confirm the middle to late Caradoc age assignment of Quinn et al. (in prep.).

In distribution, a minimum of three acritarch assemblage zones are defined from palynomorph counts and statistical analysis. These may be used locally to correlate the Winterhouse Formation in the subsurface of the Port au Port and Gulf of St. Lawrence region. The *Veryhachium* Assemblage Zone (VA Zone), found at the base of the Winterhouse Formation is defined by peak abundances of *Gloeocapsomorpha* sp., *Veryhachium trispinosum*, *Villosacapsula setosapellicula*, and *Micrhystridium fragile*. The *Micrhystridium* Assemblage



Zone (MA Zone), in the middle of the Winterhouse Formation, is marked by peak abundances of *Micrhystridium* sp. C, *Micrhystridium equispinosum*, *Veryhachium oklahomense*, *Multiplicisphaeridium* sp. B, *Micrhystridium aremoricanum*, *Comasphaeridium varispinosum*, *Multiplicisphaeridium martae*, *Polygonium* sp. C and a significant decrease in the abundance of *Villosacapsula setosapellicula* and *Veryhachium trispinosum*. The *Polygonium* Assemblage Zone (PA Zone) found at the top of the Winterhouse Formation, near the transition with the Misty Point Formation, is defined by peak abundances of *Polygonium gracile*, *Veryhachium valiente*, *Lophosphaeridium aequicuspidatum*, *Villosacapsula entrichos*, *Moyeria cabottii*, *Lophosphaeridium endense*, *Lophosphaeridium papillatum*, *Polygonium* sp. A, and the first appearance of *Cryptospore* sp. B and *Petaloferidium stigii*. Each of the three zones represent different aspects of Caradoc offshore shelf dominated environments. Differences in the assemblages of fossils correlate with changes in the depositional environments as the shelf evolved from a shallow water carbonate rich environment (the VA Zone), through a deeper water transition zone of mixed siliciclastic/carbonates (the MA Zone), and back to a shallow water environment that was carbonate poor (the PA Zone).



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Last but not least, I would like to say thank-you Randy.

## **CHAPTER 1: INTRODUCTION**

### **1.1: PURPOSE AND SCOPE**

Acritarchs are microscopic marine planktonic algae of problematic affinity, predominantly of Paleozoic age, and which are common in Paleozoic rocks in many regions around the world. Their biostratigraphic utility for Upper Ordovician correlation in North America has been shown by the recognition of comparable acritarch assemblages in strata of Anticosti Island, in the Williston Basin of Montana and South Dakota, in Ohio, Indiana, Kentucky, and Oklahoma (Jacobson and Achab, 1985; Wright and Meyers, 1981; Colbath, 1979; Loeblich, 1970a; Loeblich and Tappan, 1978; Jacobson, 1978a, b, 1979). Acritarchs are present in many marine rocks throughout the geological column. Their microscopic size and ease of extraction from rock matrices makes them ideal fossils for solving problems associated with surface, as well as subsurface geology. They are particularly useful for dating problematic Paleozoic sequences that lack other diagnostic fossils such as graptolites, brachiopods and conodonts.

The target of this work is to provide a detailed study of the acritarch assemblages for the Upper Ordovician Winterhouse Formation on the Port au Port Peninsula of western Newfoundland. The study has four objectives: (i) to illustrate and study taxonomically the Upper Ordovician acritarch flora, (ii) to evaluate the thermal maturity of the formation, (iii) to develop biostratigraphic zonations that can be used for subsurface correlation on the Port



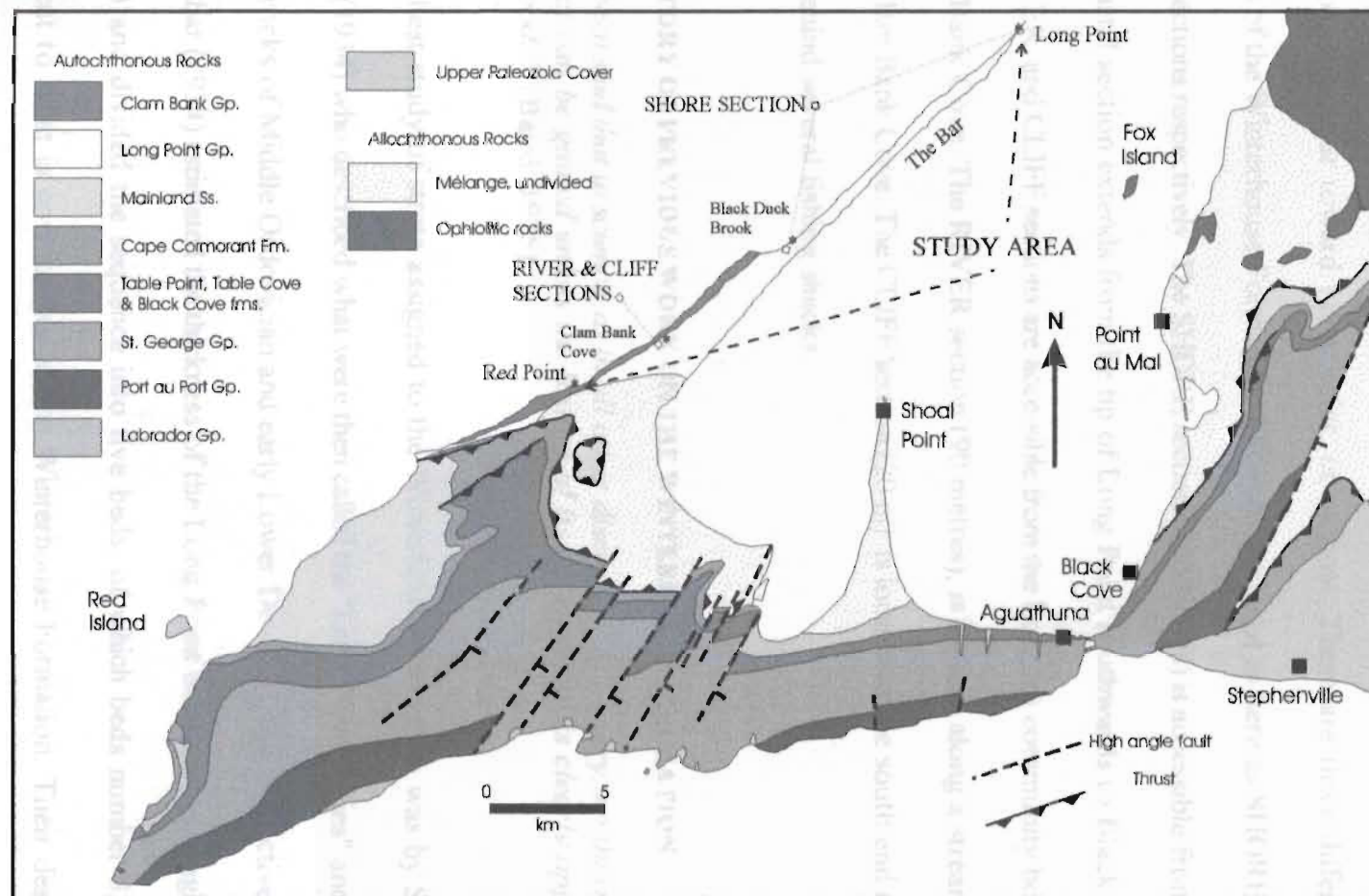
au Port Peninsula and the Gulf of St. Lawrence, and regionally for long distance correlation and (iv) to study the paleoecology of the acritarchs.

The establishment of acritarch biozones for the Upper Ordovician and correlation with well-established graptolite biozones will enable more precise biostratigraphy for Ordovician strata in Eastern North America. In a more local context, this is the first in-depth acritarch study of its kind for western Newfoundland, and it is this author's hope that this study will stimulate interest to gather similar palynological data from other formations for application to biostratigraphic problems and to ongoing subsurface hydrocarbon exploration in western Newfoundland and Gulf of St. Lawrence.

## **1.2: LOCATION AND ACCESSIBILITY**

The study area in which the Winterhouse Formation outcrops extends discontinuously some 23 kilometres along the northwest coast of the Port au Port Peninsula (Text-Figure 1.1), from the northern extremity of Long Point (N48° 47.21', W58° 45.63') south toward Red Point (N48° 39.42', W58° 59.38'). The area is covered by Canadian National Topographic System sheets 12B/6, 12B/10 & 12B/11.

The Winterhouse Formation is considered from seismic profiles of Waldron and Stockmal (1991) to extend a significant distance offshore and its orientation is consistent with that recorded by Williams (1985) from Long Ledge.



Text-Figure 1.1: The Port au Port Peninsula showing regional stratigraphy and location of study area (after Williams et al., 1996).

Accessibility is either from a paved road to Black Duck Brook and a well-maintained gravel road along The Bar toward Long Point, or by boat. There are three different sampling localities of the Winterhouse Formation. These are referred to here as SHORE, RIVER and CLIFF sections respectively. The SHORE section (350 metres) is accessible from Long Point. This coastal section extends from the tip of Long Point southwards to Black Duck Brook. The RIVER and CLIFF sections are accessible from the Lourdes community boat launch site at Clam Bank Cove. The RIVER section (90 metres), is located along a stream at the north end of Clam Bank Cove. The CLIFF section (20 m) is located at the south end of Clam Bank Cove, behind several fishing shacks.

### **1.3: HISTORY OF PREVIOUS WORK ON THE WINTERHOUSE FORMATION**

*"It has been said that in science, as in all other disciplines of inquiry, no thorough grasp of a subject can be gained unless the history of its development is clearly appreciated and understood."* (Baird, 1975).

The earliest study of strata assigned to the Winterhouse Formation was by Schuchert and Dunbar (1934) who described what were then called the "Long Point Series" and "Clam Bank Series" rocks of Middle Ordovician and early Lower Devonian age respectively. Schuchert and Dunbar (1934) estimated the thickness of the Long Point Series to be roughly 1,500 feet (457 m) and divided the sequence into five beds, of which beds number 3, 4 and 5 are equivalent to what is now known as the Winterhouse Formation. Their description is as follows:

Bed		Thickness in feet
5	(Highest known strata, exposed along Black Duck Cove, west side of Long Point Peninsula.) Greenish thin-bedded rippled calcareous sandstones, with some blue limestone and zones of greenish shale, containing, in the upper part, <i>Dinorthis</i> aff. <i>D. iphigenia</i> , <i>Hesperorthis</i> aff. <i>H. tricenaria</i> , <i>Plectorthis</i> sp., <i>Valcourea</i> sp., <i>Dalmanella rogata</i> , <i>Sowerbyella sericea</i> ? (large), <i>Rafinesquina</i> aff. <i>R. minnesotensis</i> , and, in the lower part, in a brick red sandstone, <i>Rafinesquina</i> near <i>R. deltoidea</i> . (Dip 25° N, ° 45 W). Thickness, about .....	536
4	Unstudied strata from Black Duck Brook to near lighthouse, 7 miles north along the west shore, estimated thickness.....	667
3	(Exposed at the lighthouse on both coast) Greenish- grey, somewhat rippled, calcareous shales inter-bedded with three layers of fine-grained limy sandstone and some sandy limestone, the harder beds in the upper part replete with three species of <i>Buthotrephis</i> . In the shales occur " <i>Protaroea</i> ," <i>Streptelasma</i> aff. <i>profundum</i> , an <i>anomalcystid</i> , <i>Valcourea</i> spp., <i>Dalmanella</i> near <i>D. rogata</i> , <i>Rafinesquina</i> aff. <i>R. minnesotensis</i> , <i>R. alternata</i> , <i>Sowerbyella</i> (small tumid form), <i>S.</i> aff. <i>S. undulata</i> Salter, <i>Maclurites</i> n. sp., <i>Ceraurinus</i> aff. <i>C. scosfieldi</i> , <i>Illoenous victor</i> (entire specimens), <i>Leperditia</i> . (Dip 20°N, 54 W). Thickness.....	150

Even though there were abundant fossils within the Long Point Series, the age of the Series was inferred at that time by Schuchert and Dunbar (1934, p. 72) to be Upper Ordovician due to its stratigraphic position above the Humber Arm Series. Field work carried out by Dunbar in 1920 showed that the Long Point Formation was older than the Humber Arm Series, and identification of the brachiopods by G.A. Cooper proved that they were allied to those in the Decorah shale fauna of Black River and basal Trenton, both of Middle Ordovician age (Schuchert and Dunbar, 1934 p.72). Schuchert and Dunbar (1934) interpreted the contact between the Clam Bank and the Long Point formations as unconformable; but they did not

recognize the partial overturning of the two formations (Fåhræus, 1973). Schuchert and Dunbar (1934), stated that a fault contact between the Long Point and the Clam Bank formations might be seen near the waterfall at Clam Bank Cove. This fault has not been identified by subsequent workers.

Sullivan (1940) studied the Long Point strata and changed its lithostratigraphic status from Series to Group. As reported in Riley (1962), Sullivan divided the Long Point Group into seven units, the upper four of which were equivalent to the Winterhouse Formation. Sullivan's description which follows is from a composite section measured downward from what he considered to be the contact with Clam Bank group at Misty Point.

Bed		Thickness in feet
7	Thin-bedded, knobby limestone with occasional sandstone layers. Greenish grey. Very fossiliferous, containing <i>Dinorthis</i> cf. <i>D. iphigenia</i> (Billings), <i>Hesperorthis tricenaria</i> (Conrad), <i>Dalmanella rogata</i> (Sardeson), <i>Sowerbyella sericea</i> (Sowerby), and <i>Rafinesquina</i> cf. <i>R. minnesotensis</i> (Winchell). Thickness.....	300
6	Slabby, greenish grey, sandy limestone beds, sparsely fossiliferous. Exposed near inner part of cove at Black Duck Brook. Thickness.....	090
5	Thin-bedded knobby limestone, light grey, interbedded with greenish-grey shaly layers. A few sandstone layers. Almost entirely unfossiliferous. Exposed along west shore of Long Point between Black Duck Brook and lighthouse. Thickness.....	443
4	Limestone conglomerate with boulders up to 2 feet in diameter, exposed 1/2 mile south of lighthouse on west shore of Long Point. Thickness.....	004
3	Shaly, sandy limestone and interbedded shale beds. Found near lighthouse on both sides of point. Sparsely fossiliferous, with	

<i>Leperditia fabulites</i> (Conrad)	most abundant form.	170
Thickness.....		

The fossil fauna collected from the top of the Lourdes Formation by Sullivan (1940) enabled him to correlate it with the Black River and basal Trenton of New York, both of middle Ordovician age.

Rodgers (1965) studied the stratigraphy of the Long Point Formation but failed to include the Winterhouse Formation. He did interpret the contact between the Long Point Group and the Humber Arm Allochthon at Tea Cove as an unconformity. He also stressed the importance of the age of the succession to an understanding of the regional structure of the western Appalachians.

Kay (1969) divided the Long Point Formation into four units, of which unit 4, a shaly and sandy bed of indeterminate thickness, is believed to be that of the Winterhouse Formation. No paleontology was carried out.

O'Brien (1973) in her study of the stratigraphy and paleontology of the Clam Bank Formation, and the upper part of the Long Point Formation, divided the Long Point Formation into two units. A lower Misty Cove member, roughly equivalent to the Shore section of this work, and an upper red Lourdes member, now the Misty Point Formation of

Quinn et al., (in prep.). Her find of an Ordovician gastropod fairly high in the red Lourdes member which had been referred to the Silurian Clam Bank Formation, has subsequently been re-assessed by Quinn et al.(in prep.).

Fåhræus (1973) also established zonations within the Long Point Formation by using conodonts, but did not divide this formation into the Lourdes and Winterhouse as we know it today. Instead he divided the Long Point Formation into seven lithological units. Of the seven subunits described only one, unit G, can be included in the Winterhouse Formation. This unit is made up from a composite of sites, similar to those described herein. Area 1 at the northern half of the northwestern shore of Long Point, area 2 along the middle third of the western shore of Long Point and area 3, along a stream discharging into the northern part of Clam Bank Cove. Fåhræus, after Weerasinghe (1970), considered the boundary between the Winterhouse (unit G) and the underlying Lourdes (unit A-H) as transitional. Fåhræus (1973, p.1829-30) was also the first to provide a detailed measured section and interpretation of the depositional environment for the Winterhouse Formation. He noted two clearly distinguishable major lithological trends within the Winterhouse Formation; (i) an increase in clastic components at the expense of the carbonate sedimentation, and (ii) a gradual transition into coarser, less well sorted, reddish sands. He interpreted the depositional environment of the Winterhouse Formation as that of a prograding fluviomarine delta. Fåhræus concluded that the boundary of the Long Point Formation and the overlying Clam Bank Formation was a discontinuity at the top of a cross bedded, pebbly gravel conglomerate (his location for this



discontinuity was not clearly identified). The present author observed this distinctive bed just a 10 minute walk north of the river section. Since these beds are overturned in the immediate area, this part of the section is well up on the shore face. Fåhræus (1973, p. 1830) recovered conodont species, typical of the North American Midcontinent Faunal Province, from a biosparite occurring in horizon III in area 2 of unit 3. Species included *Belodina compressa*, *Drepanodus suberectus*, *Panderodus gracilis*, *Phragmodus undatus*, *Polyplacognathus ramosa*, and *Tetraprioniodus delicatus*, as well as some distacodiform and oistodiform elements. Fåhræus was unable to correlate his conodont assemblage unequivocally except for the shortest ranging species *Polyplacognathus ramosa* which he was able to correlate with either the upper part of the *A. tvarensis* Zone in the Trenton Group of New York and Ontario, or tie it into the Cincinnati Region where *P. ramosa* had been found in strata that belong in the lowermost part of the *A. superbis* Zone by Sweet and Bergström (1971, p. 623). Ages in both instances are lower and upper Caradoc respectively.

Bergström et al. (1974, p. 1627) formalised the stratigraphy by establishing the Long Point Group with two new formations, the Lourdes and the Winterhouse formations. Bergström and his co-workers estimated a total thickness of 1000 ft. (300 m) for the thin-bedded silty shales, sandstones, redbeds and occasional limestones of the Winterhouse Formation. His section only included that portion partially exposed on the northeast side of Long Point Peninsula from Black Duck Brook (Misty Point) north 13 km to the lighthouse. This shore section is today considered to be the type section for the Winterhouse Formation (Williams

et al., 1985). Bergström et al. (1974) also described the contact between the Lourdes and the Winterhouse as transitional but were unable to verify the contact between the Winterhouse Formation and the overlying Clam Bank Formation. Their evidence for the age of the various parts of the succession was given on the basis of brachiopods, conodonts, and graptolites. Specimens of *Macrocoelia* and *Machurites* present in the gradational contact between the Lourdes and the Winterhouse suggest a Middle Ordovician age. This was in agreement with conodonts found in the lower part of the Winterhouse (Fåhræus, 1973), unfortunately the exact location that Fåhræus is referring to has not been determined. Beds of siltstone and shale located directly above a conglomerate bed some 135 ft (41m) above the base of the Winterhouse yield two graptolite species. These species, identified as *Glyptograptus* and a short, stubby climacograptid, were considered by Riva (in Bergström et al., 1974 p. 1631) to indicate an Upper Ordovician Cincinnati age. The apparent hiatus between the two graptolite sites (Bergström et al. 1974) was attributed to a time period when the Lourdes Formation was eroded and provided the limestone material to the boulder beds in the lower portion of the Winterhouse during the Taconic orogeny.

Dean (1977) studied trilobites from four localities within the Winterhouse Formation. The lower most Winterhouse Formation yielded *Flexicalymene* sp. This genus was interpreted by Dean (1977), based on analogy with other North American records, to indicate Barneveldian or late Wilderness age. Species of *Calyptaulax* and *Isotelus* in the highest beds of the Winterhouse Formation were interpreted to represent long ranging Ordovician genera and to

give no precise indication of age.

Martin (1978) undertook a study of the Lower Paleozoic chitinozoans and acritarchs of Newfoundland and investigated two localities from high in the Winterhouse Formation. Both samples yielded chitinozoans and acritarchs. Chitinozoa species included: *Hercoclitina* aff. *H. downiei*, *Kalochitina multispinata*, and *Ancyroclitina alaticornis*. These species enabled Martin (1978) to assign a Caradoc age for the uppermost part of the section. Acritarch species recovered during her investigation did not permit such precise age assessment as the species present were long ranging. These included *Multiplicisphaeridium bifurcatum* which is known from the Middle Ordovician of Anticosti Island and Gotland as well as from Caradoc and Ashgill series of Belgium, *Goniosphaeridium polygonale* and *Peteinosphaeridium breviradiatum*, which are long ranging species in the Ordovician in Europe and in the Chazy, Trenton and Utica groups of the central St. Lawrence Platform, and one specimen found of *Actipilion* aff. *A. druggii* which could only be correlated with similar types described from the Upper Ordovician Sylvan Shale of Oklahoma.

Schillereff and Williams (1979, p. 329) while mapping the geology of the Stephenville - Port au Port area, interpreted the contact between the Clam Bank Formation and the underlying Long Point Group as gradational and conformable. They did not take O'Brien's (1973) work on the Clam Bank Group into consideration during their regional mapping of the Port au Port and subsequent work by Quinn et al. (in prep.) has since provided new evidence to suggest

that this contact is not a contact between two Groups, but rather represents a change in the depositional environment within the Winterhouse Formation of the Long Point Group.

Williams (1985), while mapping the Stephenville area, located the Lourdes - Winterhouse boundary as a planar surface of erosional disconformity in the Black Duck Brook section. This disconformity, between nodular reefy limestone below and thin bedded limestone, siltstone and shale above, provided a readily identifiable boundary between units of the Long Point Group. This boundary is now known to be somewhat above the accepted Lourdes - Winterhouse contact (Williams, 1995).

Stait and Barnes (1991) in their study of the stratigraphy of the Middle Ordovician Long Point Group concentrated mainly on the detailed stratigraphy of the Lourdes Limestone. Their work did not provide any new information on the stratigraphy of the Winterhouse Formation and in all instances agreed with previous work completed by Schuchert and Dunbar (1934), Rogers (1965), Fåhræus (1973) and Bergström et al. (1974). Stait and Barnes (1991, p.243) did acknowledge several fossiliferous horizons within the Winterhouse Formation which contained receptaculitids, brachiopods, nautiloids, rugose corals, gastropods, conodonts, graptolites, and trilobites. The present author believes this to be in error and suggests that Stait and Barnes (1991) were referring to fossils of the Long Point Group since no occurrence of in situ rugose corals have been seen in the Winterhouse Fm.

Waldron and Stockmal (1991) provided the first detailed structural analysis of the Long Point-Clam Bank succession. Their correlation of onshore geology with offshore multichannel seismic profiles provided structural evidence for east-vergent thrusts and west-vergent folds and thrusts in the general region of the Port au Port Peninsula. Waldron and Stockmal (1991) interpreted the contact at Tea Cove as “a thrust, beneath which the rocks of the Humber Arm Allochthon were transported westward after deposition of the Long Point-Clam Bank succession; the thrust marked the upper detachment of an Acadian triangle zone” and attributed the overturning of the Long Point-Clam Bank succession west of Lourdes as the “result of thrust-sense movement along the Round Head Shear Zone,” during the Devonian and subsequent Carboniferous. This information suggests that the Long Point-Clam Bank groups were thrust eastward above the Humber Arm Allochthon and that the underlying Cambrian-Ordovician carbonate sequence and Humber Arm Allochthon have all been transported with respect to underlying rocks (Williams et al., 1995, p. 386).

Williams et al. (1995) introduced the term “Clam Bank Belt” as a small outcrop area of Middle Ordovician to Devonian rocks along the western shore of the Port au Port Peninsula that included both Long Point and Clam Bank groups. No new data were however included. Williams et al. (1995, p.384) stressed the importance of rocks in this belt, which in the traditional model recorded the deposition and deformation between the Middle Ordovician emplacement of the Humber Arm Allochthon and deposition of Carboniferous cover rocks.

The Clam Bank Belt projects along strike 20 km seaward off the northwest tip of Long Point and provides a record of rocks and relationships otherwise hidden in the Gulf of St. Lawrence. Williams et al. (1995, p.386) were the first to suggested that the top of the Winterhouse Formation or the top of the Long Point Group was exposed in a stream section at Clam Bank Cove (this author's river section). This portion of the section contains a grey sandstone that passes upward into maroon to reddish sandstone. Recent work (Quinn et al., in prep.) has shown that this section of the Winterhouse Formation does not represent the top of the Long Point Group, but rather represents a change in depositional environment from the Winterhouse Formation and the newly defined Misty Point Formation, both of which are formations within the Long Point Group.

Most recently Quinn et al. (in prep.) have studied the siliciclastic sediments and paleontology of the Long Point-Clam Bank succession. They propose that the Winterhouse Formation be divided into two formations, the Winterhouse Formation which consists of grey siliciclastics with minor calcarenites and limestone conglomerates, and the Misty Point Formation which consists of the red sandstones. Traditionally these red sandstones located at Misty Point have been described and assigned to the Clam Bank Formation (Schuchert and Dunbar, 1934; Riley, 1962; Rodgers, 1965; Fåhræus, 1973; Bergström et al., 1974; Schillereff and Williams, 1979; Williams, 1985; Williams et al., 1995; Waldron and Stockmal, 1991; and Stait and Barnes, 1991). However, Quinn et al. (in prep.) discovered a fossil locality at the Misty Point section which is rich in brachiopods, gastropods, and trilobites of Late Ordovician age

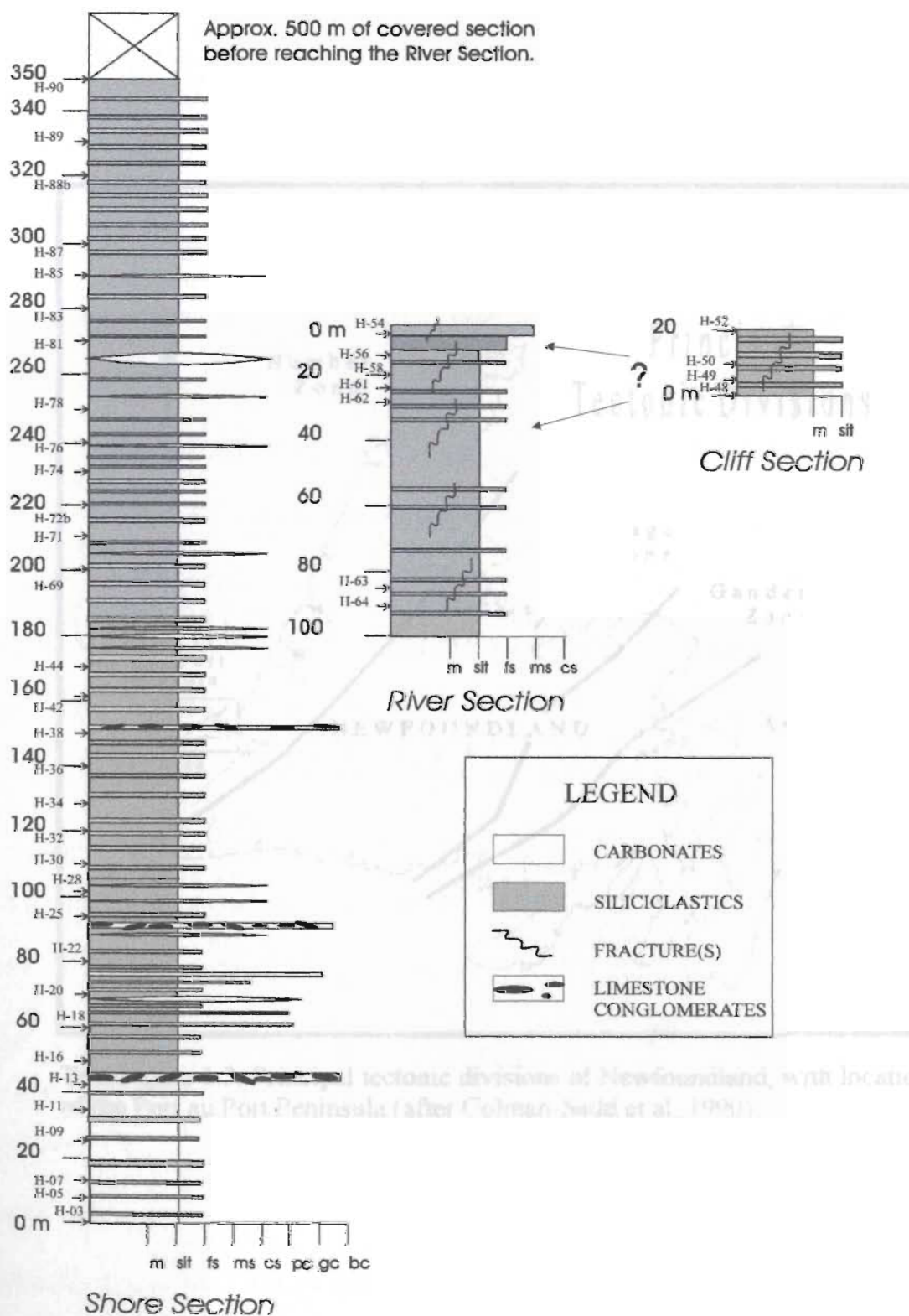
(Caradoc-early Ashgill). This age is in agreement with previous work carried out by O'Brien (1973) in her work on the Clam Bank Formation. Quinn et al. (in prep.) interpret the depositional environment of the Winterhouse Formation as a prograding sequence with the Lower Winterhouse Formation representing offshore deposits, and the Misty Point Formation representing marginal marine/deltaic deposits.

This author after reviewing Quinn et al.'s (in prep.) work, and studying the Winterhouse sections while collecting field samples, agrees with her interpretation and stratigraphic divisions and has chosen (with Quinn's permission) to use Quinn's stratigraphic sections to correlate and place sample locations (Text-Figure 1.2).

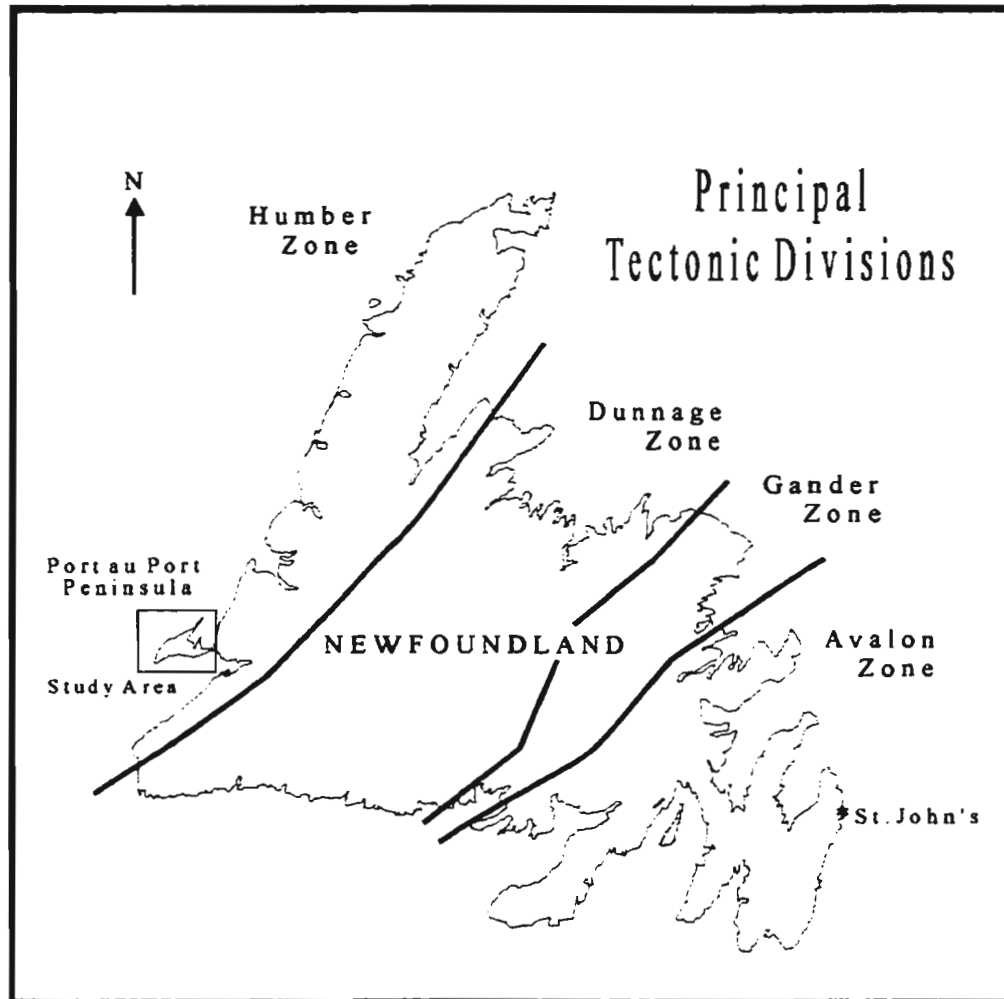
#### **1.4: REGIONAL GEOLOGICAL SETTING**

Newfoundland lies in the northeastern Canadian Appalachian Region and provides a well-exposed cross-section through the Appalachian Orogen. It has been divided into four major tectono-stratigraphic zones (Text-Figure 1.3) based on contrasts in stratigraphy and structural style of mid-Ordovician and older rocks which have themselves been internally subdivided. From west to east these tectono-stratigraphic zones are: Humber, Dunnage, Gander, and Avalon (Williams, 1978, 1979, 1995; Williams et al., 1988; Colman-Sadd et al., 1990).





Text-Figure 1.2: Stratigraphic sections of the Winterhouse Formation (after Quinn et. al., in prep.). Sampling intervals are designated with the letter (H-).



Text-Figure 1.3: Principal tectonic divisions of Newfoundland, with location of the Port au Port Peninsula (after Colman-Sadd et al., 1990).

The study area on the Port au Port Peninsula, in which the Winterhouse Formation occurs, lies within the **neautochthonous** sequence of the Humber Zone. The geology of the Humber Zone records the evolution and destruction of the ancient continental margin of eastern North America during the opening and subsequent closure of the Iapetus (Proto-Atlantic) Ocean during late Precambrian through Palaeozoic times (Williams, 1978, 1979, 1995). Within this zone **parautochthonous** shallow-water sediments are tectonically overlain locally by **allochthonous** deep-water strata and ophiolites which were placed onto the platform during the Taconic Orogeny (Williams and Stevens, 1974; Williams, 1995). Both parautochthonous and allochthonous strata are in turn overlain by a **neautochthonous** sedimentary sequence of late Ordovician to early Devonian age, and basin-fill predominantly terrestrial Carboniferous rocks (Quinn et al., in prep.; Schillereff and Williams, 1979; Williams and Cawood, 1989; Williams, 1995). The eastern margin of the Humber Zone is drawn at the Baie Verte-Brompton Line where a steep structural belt is marked by deformed ophiolites and mafic volcanic rocks (Williams and St. Julien, 1982). The Dunnage zone represents vestiges of the Iapetus Ocean, while the Gander and Avalon zones represent terranes that lay to the east of the Iapetus respectively (Williams, 1979, 1995).

#### 1.4.1: PARAUTOCHTHONOUS ROCKS

In western Newfoundland, deposition of parautochthonous rocks, which represent mainly continental shelf and shallow water carbonate deposits, was initiated on rifted and block-faulted Grenvillian basement (Knight et al., 1995). This irregular basement was thinly covered

and then buried by an onlap-offlap late Precambrian to early Middle Cambrian succession of siliciclastic and carbonate sediments assigned to the Labrador Group (James et al., 1989). The Labrador Group was succeeded by shallow water carbonate platform deposits consisting of peritidal carbonates of the Middle to Upper Cambrian Port au Port Group (Chow, 1986), muddy carbonates of the Lower Ordovician St. George Group (Knight and James, 1987), and finally carbonates of the Middle Ordovician Table Head Group (Klappa et al., 1980). Carbonates of the Table Head Group record the collapse and destruction of a long lived carbonate platform in response to the initiation of the Taconic Orogeny (Klappa et al., 1980; Stenzel et al., 1990; Pitman, 1991). Overlying the carbonate succession are the Ordovician siliciclastic foreland basin fill (flysch) of the Goose Tickle Group (Quinn, 1995; Schillereff and Williams, 1979; James et al., 1989) that heralded the arrival of allochthonous sequences from the southeast (Quinn, 1995).

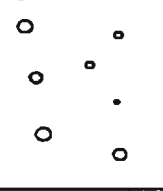
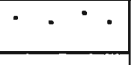
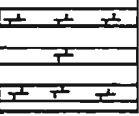
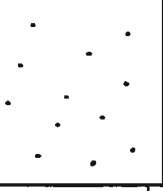
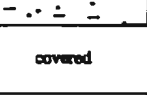
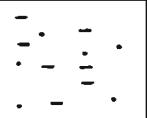
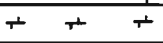
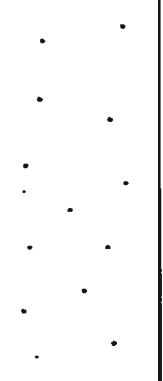

#### 1.4.2: ALLOCHTHONOUS ROCKS

In western Newfoundland, Port au Port region, the parautochthonous succession is structurally overlain by a westerly transported Taconic thrust complex known as the Humber Arm Allochthon. The Humber Arm Allochthon consists of imbricated slices of upper Proterozoic to middle Ordovician deep-water sediments of the Cow Head Group (Kindle and Whittington, 1958; James and Stevens, 1986) and the Curling Group (Stevens, 1970; James et al., 1989); igneous and metamorphic rocks of the Skinner Cove Volcanics and Little Port Complex; and ophiolites of the Bay of Islands Complex (Williams, 1995).

#### 1.4.3: NEOAUTOCHTHONOUS ROCKS

Deposition of the mid-Middle to Upper Ordovician Long Point Group, which contains the Winterhouse Formation, marked the first phase of post-Taconic sedimentation (Bergström et al., 1974; Pitman, 1991; Knight et al., 1995) and represents the oldest cover rocks above the Humber Zone allochthons (Williams, 1995, p.47). Carbonates and clastics of the Long Point Group (Upper Ordovician) have been interpreted as representing a late phase of foreland basin deposits (Quinn, 1995) that occurred on the relatively low relief foundering and deformed Iapetan margin (James et al., 1989). Disconformably overlying the Long Point Group are the crossbedded red sandstone and red and green shales of the Silurian-Devonian Clam Bank Group which have been considered to represent a post-Taconic sequence of foreland basin fill (Quinn et al., in prep.). These basin fill deposits are in-turn overlain by Carboniferous cover rocks. It should be noted here that even though these rocks are termed neautochthonous they are not structurally in place and have undergone limited transport to their present location. As such, they have been included under Autochthonous Rocks in Text-Figure 1.1. Both the Long Point Group and Clam Bank Formations have been generally considered to represent a post-Taconic sequence of foreland basin fill (Quinn et al., in prep.; Waldron et al., 1993; Calwood, 1993; Hibbard, 1994).

Text-Figure 1.4 illustrates the stratigraphic position of the Winterhouse Formation in the regional stratigraphy of the Port au Port Peninsula.

Late Silurian	Clam Bank Formation	upper Clam Bank Formation		
		middle Clam Bank Formation		
		lower Clam Bank Formation		
				?
Late Ordovician	Long Point Group	Misty Point Formation		River and Cliff Sections
		Winterhouse Formation		
				Shore Section
		Lourdes Formation		
				?
Middle Ordovician	Goose Tickle Group	Mainland Formation		
	Table Head Group	undivided		

Text-Figure 1.4: Stratigraphic section of the Port au Port Peninsula, with location of the Shore, River and Cliff sections (after Quinn et al., in prep.).

## **CHAPTER 2: METHODOLOGY**

### **2.1: FIELD WORK**

Field work was carried out in September, 1995. Dr. Henry Williams in consultation with Dr. Louise Quinn showed Dr. Elliott Burden and the author the sections and areas of special interest. In particular, the top of the Winterhouse section at Lourdes, where the Winterhouse Formation is overlain by the Clam Bank Formation, and the bottom of the section, located north of the lighthouse, where the Winterhouse Formation is underlain by the Lourdes Formation. Other localities of interest included previously sampled strata that had been collected for conodont and graptolite studies (Bergström et al., 1974; Fåhræus, 1973). Mapping was carried out using 1:15,840 aerial photographs and an Apelco 15 handheld GPS (global positioning system). A Jacob's staff and Silva compass were used to measure the section. All the samples taken from the Winterhouse Formation are tied to the measured section of Quinn et al. (in prep.) in Text-Figure 1.2.

### **2.2: SAMPLING PROCEDURES**

Palynology samples were collected from the Winterhouse Formation at 5 metre intervals from the shaly or silty beds, unless lithology or lack of exposure dictated otherwise. To avoid contamination between samples, each was placed into a twist lock sterile plastic bag. If graptolites were noted to be present in the outcrop, hand samples were taken for analysis.



### 2.3: SAMPLE PREPARATION

Due to the minute size of acritarchs, the utmost care was employed throughout the sample processing procedure to avoid cross contamination, not only between samples used in this study, but from other palynology samples being processed at Memorial University's palynology research laboratory. Work surfaces as well as laboratory equipment underwent thorough cleaning prior, during and after use.

Palynology samples were first washed with distilled water and scrubbed with a wire brush to remove loose fragments and surface debris. After drying, samples were crushed to pea size fragments. Fragments showing weathered surfaces were then removed. Approximately 10 to 25 gram samples were weighed into appropriate labelled beakers and 4 *Lycopodium* tablets having concentrations of  $(13,500 \pm 300)$  each) were added for fossil concentration calculation.

Standard processing techniques were employed which included acid digestion using 20% hydrochloric acid to remove carbonates and 48% concentrated hydrofluoric acid to remove silicates. Samples were washed with distilled water and centrifuged between all acid changes. After acid treatment and washing, an unsieved slide was made to determine if further treatment was necessary, after which acritarch residues were sieved through a 10 $\mu$ m Nitex monofilament screen to remove clays. At this stage, two more slides were made and labelled **unox or siev** for future reference. If the acritarchs were unrecognisable, because of their transparent colour, further treatment was implemented. This included oxidation with a

Schultze's solution and staining with Sarfranin O biological stain, after which two more slides were made and labelled **oxid** for future reference. Unfortunately, in many instances oxidized acritarchs did not take the stain.

#### **2.4: SLIDE PREPARATION**

Permanent slides were made with a drop of one percent solution of Polyvinyl Alcohol mixed on a coverslip with a pipetted drop of organic residue. Coverslips containing dried residue were inverted and glued with Elvacite bioplastic to a standard microscope slide. If samples were to be viewed by scanning electron microscopy (SEM) a different procedure was employed. This consisted of evenly distributing a drop of organic residue onto a 1 cm glass coverslip covered with a copper SEM grid. As the residue dried the copper grid dried into place with the coverslip. The 1 cm coverslip was temporarily placed on a microscope slide for viewing, and for locating specimens that were to be viewed and photographed using the SEM. The coverslip, along with the attached grid, was then fixed onto an aluminum 1 cm SEM stub and coated with gold for SEM viewing and photography.

#### **2.5: PHOTOGRAPHY, CURATION and PLATE NOMENCLATURE**

All the figured specimens, residues and field samples used in this study are stored in the palynological collections in the Department of Earth Sciences at Memorial University of Newfoundland (MUN). Specimens were viewed and photographed using a Zeiss photo microscope. SEM photos were taken using a Hatachi 500 housed at the Department of

Biology at MUN.

Plates are in numerical order, along with a list of numbered figures which illustrate designated specimen(s). After the figure number, the specimen is named, followed by its original author. A slide or SEM reference number follows, starting with the letter P (e.g. P95287 3/3 unox). This number is a catalogue processing number. Following the catalogue number is a grid reference. For transmitted and fluorescence light pictures the grid reference refers to the England Finder reference system (e.g. J20/0). For SEM pictures the grid reference is a letter and a number (e.g. U5). The SEM grid used was a JBS#799-22 copper 10mm diameter grid. The grid is divided into 400 fields. Patterns on the grid bars help to identify the areas where examinations are carried out. The author used a letter and a number for the grid reference instead of the surface patterns. There are 20 equal units along the x-axis, which were numbered (1 to 20), and 20 equal units along the y-axis, which were lettered (a to t), the top of the stub was always north and the grid was oriented so that the numbers ran north to south and the letters ran west to east. Magnification used in the illustration is designated by the letter x (e.g. x350).

## **2.6: SOME FACTORS THAT AFFECT SAMPLE RELIABILITY**

The advantages of palynomorphs in biostratigraphical studies are their small size and their resistance to conditions encountered at the depositional site. Unfortunately, the same attributes that make them resilient can make them problematic in palynological studies

because of the probability of reworking, leaching, stratigraphic leakage and contamination.

REWORKING refers to the redeposition of older palynomorphs into younger sediments. If reworked fossils are present they are indigenous to the study material and cannot be avoided. In most instances they can be identified by comparing their state of preservation or thermal maturity relative to that of others present in the study material. Often times they are more corroded in appearance and darker in colour than in-situ forms. When the true ranges have been determined it will be easier to differentiate between indigenous taxa and those incorporated into the sediment as a result of reworking. However, this assessment becomes more difficult when the times separating in situ and reworked taxa are short. Diagnostic reworked palynomorphs have one redeeming quality; if present they can assist in identifying the sediment source (Turner, 1982).

LEACHING refers to the selective removal of flora from the study material. It may result from size fractionation as a result of hydrodynamics in the depositional cycle or selective chemical degradation of all or specific species because of their chemistry or the chemistry of the surrounding hydrothermal fluids (Traverse, 1988). Such leaching is very difficult to identify and in most instances goes unnoticed.

STRATIGRAPHIC LEAKAGE is the opposite of reworking in that it refers to the deposition of younger palynomorphs into older sediment. The most common mechanism for leakage is

when younger sediments are deposited in cracks, fissures, or solution channels. It can be recognized through maturation studies or by the simultaneous occurrence of two species which do not have synchronous ranges.

CONTAMINATION refers to the introduction of recent, synchronous or older palynomorphs into study material. This can occur through improper collecting, handling and processing procedures; or through transportation of palynomorphs in surface waters. In most instances contamination can easily be identified using the same methods as those employed for reworking and leakage, mainly through differences in age and thermal maturity.

The above processes are difficult to recognize and harder, if not impossible, to routinely distinguish. The Winterhouse Formation does not appear to suffer from contamination or leakage. There is a possibility of leaching where beds become progressively coarser and less carbonate rich towards the top. This is noticeable with the *Micrhystridium* species in particular and other smaller forms that are dominant in the shore section, but become less common in the river and cliff sections (e.g. the top of the section). There is also a slight increase in the frequency, thermal maturity and preservation of *Moyeria cabottii* Cramer 1970, *Petaloferidium stigii* Jacobson 1978b, *Petaloferidium* sp. , and *Cryptospore* sp. B towards the top of the section. This may be the result of reworking (?) or change to an environment in which these particular species are more likely to be deposited.

Reworking, in particular, is very difficult to determine for species in the Winterhouse Formation because of the diachronous ages of the species in question.

## CHAPTER 3: PALYNOMORPH PALEONTOLOGY AND MATURATION

### 3.1: INTRODUCTION

The taxonomic descriptions presented here are literature based and no type material was examined. Because this thesis attempts to describe and illustrate all of the acritarch flora in the Winterhouse Formation, some species are only represented by a few specimens. Acritarchs are included under Algae Incertae Sedis; their unknown affinity prohibits their inclusion in a biological classification scheme. No reference is given to the artificial subgroups of Downie et al. (1963), Evitt (1969), Diver and Peat (1979) or Tappan (1980). Following Colbath's (1979) classification *Cymatiosphaera* and *Leiosphaeridia* are included in the Class Prasinophyceae; *Cymatiosphaera* for its similarity to cysts of *Pterosperma* and *Leiosphaeridia* for its similarity to cysts of the motile green alga *Halosphaera*. Unknown terrestrial (?) species are present and described. These species are described under the category of Cryptospores following Richardson's (1996) revised classification scheme.

It is the hope of this author, as with previous authors, that describing the genera in alphabetical order will encourage the use of the findings presented in this thesis. Some comments on the various headings used in the taxonomic section are listed below.

### **3.2: METHODS**

#### **3.2.1: DESCRIPTION**

The descriptive morphologic terminology and abbreviations used are essentially those of Tappan and Loeblich (1971), Kjellström (1971a), Colbath (1979) and Playford et al. (1995); no new descriptive terms are introduced. Taxonomically useful morphologic features used in the classification of genera and species (after Downie et al., 1963 and Sarjeant and Stancliffe, 1994) are:

- 1) The shape and size of the vesicle;
- 2) Size of the ornamentation and its areal distribution on the vesicle wall;
- 3) Whether the vesicle is single or multi layered;
- 4) The process type, formula and its sculpture, and if it controls the shape of the vesicle;
- 5) Whether the processes are of single order of branching or of two or more orders;
- 6) Whether the processes are hollow or solid; if hollow whether or not their cavity communicates with the vesicle interior; the proportion of the cavity size to process length and whether the base is closed by a simple wall layer or by a thick plug;
- 7) The excystment type.

The taxonomic descriptions are laid out in a standard manner and refer to species as seen through light microscope in compressional view, unless stated otherwise. Processes, when counted, are only counted on one side of the vesicle in the optical view.



### 3.2.2: SYNONYMY

Synonyms were kept short. The first reference in the synonymy list is the author who provided the original diagnosis. The second, marked by an asterisk (\*) includes more recent authors who have included a complete up to that date synonymy list. Readers are referred to those authors publications for the complete list of synonym. It should be noted here that because of the ongoing debate with regard to the correct synonymy for *Micrhystridium*, *Goniosphaeridium*, and *Polygonium*, this author has chosen to maintain *Micrhystridium* and to have *Goniosphaeridium* included as a junior synonym of *Polygonium*. This follows recent taxonomic amendments proposed by Sarjeant and Stancliffe (1994).

### 3.2.3: MEASUREMENTS

For all species the dimension(s) of the vesicle is taken along with those of the processes where applicable. For spherical forms the diameter (Vd) is taken for the vesicle size; for triangular forms (Vd) refers to the longest measurement along the side of the vesicle between two processess. For rectangular or similar forms (Vl) refers to vesicle length and (Vw), vesicle width. The process dimensions include process length (Pl) which is that measurement taken from it's tip (expanded tips not included) to the base where it attaches itself to the vesicle, and process width (Pw) which is that measurement taken at the base of the process where it joins to the vesicle. Number of processes (Pn) is given if counted, along with the number of specimens measured (Sm). When more than one specimen is measured, two measurements are given, the largest and the smallest. In practice, the author tried to measure a minimum of

10 specimens of the same species, this was at times very difficult to achieve due to the low abundances of some species.

### 3.3: SYSTEMATIC PALEONTOLOGY

#### 3.3.1: TAXONOMIC LIST OF SPECIES PRESENT

##### Algae Incertae Sedis

*Actinotodissus crassus* Loeblich and Tappan 1978

*Actipilion druggii* Loeblich 1970a

*Ammonidium parvipinnatum* (Uutela and Tynni) comb. nov.

*Axisphaeridium tricolumnelar* Uutela 1989

*Bacisphaeridium* sp.

*Baltisphaeridium accinctum* Loeblich and Tappan 1978

*Baltisphaeridium aspersilumiferum* Loeblich and Tappan 1978

*Baltisphaeridium brevifilicum* Kjellström 1971a

*Baltisphaeridium filosum* Kjellström 1971a

*Baltisphaeridium nanninum* Eisenack 1965b

*Baltisphaeridium* sp.

*Baltisphaerosum dispar* Turner 1984

*Cheleutochroa diaphorosa* Turner 1984

*Cheleutochroa* sp.

*Comasphaeridium lanugiferum* Jacobson and Achab 1985

*Comasphaeridium varispinosum* Uutela 1989

*Comasphaeridium* sp. A

*Comasphaeridium* sp. B

? *Comasphaeridium* sp. C

*Dicommopalla macadamii* Loeblich 1970b

*Excultibrachium concinnum* Loeblich and Tappan 1978

*Gloeocapsomorpha* sp.

*Gorgonisphaeridium* sp. A

*Gorgonisphaeridium* sp. B

*Leiofusa fusiformis* Eisenack 1934 ex Eisenack 1938

*Lophosphaeridium aequicuspdatum* Playford and Martin 1984

*Lophosphaeridium edenense* Loeblich and Tappan 1978

*Lophosphaeridium papillatum* (Staplin) Martin 1969

*Lophosphaeridium papulatum* Martin 1983

*Lumulidia* sp. A

*Lumulidia* sp. B

*Micrhystridium acuminosum* Cramer and Díez 1977

*Micrhystridium aremoricum* (Paris and Deunff) Fensome et al. 1990

*Micrhystridium equispinosum* Turner 1984

*Micrhystridium fragile* Deflandre 1947

*Micrhystridium shinetonense* Downie 1958

*Micrhystridium* sp. A

*Micrhystridium* sp. B

*Micrhystridium* sp. C

*Moyeria cabottii* (Cramer) Miller and Eames 1982

*Multiplicisphaeridium irregulare* Staplin et al. 1965

*Multiplicisphaeridium martae* Cramer and Díez 1972

*Multiplicisphaeridium* sp. A

*Multiplicisphaeridium* sp. B

*Navifusa similis* (Eisenack) Turner 1984

*Ordoviciidium groetlingboenis* (Kjellström) Loeblich and Tappan 1978

*Ordoviciidium heteromorphicum* (Kjellström) Loeblich and Tappan 1978

*Ordoviciidium* sp.

*Petaloferidium stigii* Jacobson 1978a

*Petaloferidium* sp.

*Poikilofusa* sp. cf. *P. spinata* Staplin et al. 1965

*Polyancistrodorus* sp. cf. *P. columbariferus* Loeblich and Tappan 1969

*Polygonium connectum* (Kjellström) Sargent and Stancliffe 1994

*Polygonium gracile* Vardrová 1966

*Polygonium tenuispinosum* Uutela and Tynni 1991

*Polygonium* sp. A

*Polygonium* sp. B

*Polygonium* sp. C

*Pterospermella* sp.

*Rhachosoarium lappaceum* Tappan and Loeblich 1971

*Uranidium semicalvum* Jacobson and Achab 1985

*Veryhachium downiei* Stockmans and Willièrè 1962

*Veryhachium oklahomense* Loeblich 1970a

*Veryhachium rhomboidium* Downie 1959

*Veryhachium trispinosum* (Eisenack) Stockmans and Willièrè 1962

*Veryhachium valiente* Cramer 1964

*Villosacapsula entrichos* (Loeblich) Loeblich and Tappan 1976

*Villosacapsula irroratum* (Loeblich and Tappan) Fensome et al. 1990

*Villosacapsula setosapellicula* (Loeblich) Loeblich and Tappan 1976

#### Class Prasinophyceae

*Cymatiosphaera* sp. A

*Cymatiosphaera* sp. B

*Leiosphaeridia* ssp.

#### Cryptospores

Cryptospore sp. A

Cryptospore sp. B

## 3.3.2: SYSTEMATIC DESCRIPTIONS

**Algae Incertae Sedis****GENUS *Actinotodissus* Loeblich and Tappan 1978**

TYPE SPECIES: *Actinotodissus longitaleosus* Loeblich and Tappan 1978

***Actinotodissus crassus* Loeblich and Tappan 1978**

Plate 1, fig. 1

*Actinotodissus crassus* Loeblich and Tappan, 1978, p. 1238-1241, pl. 1, fig. 5-7;  
Jacobson and Achab, 1985, p. 171, pl. 1, figs. 1, 2.

*Actinotodissus* cf. *A. crassus* (Loeblich and Tappan) Molyneux and Paris, 1985, p. 12,  
pl. 1, figs. 1, 2; Molyneux, 1988, p. 45, pl. 8, figs. 1, 2.

**DESCRIPTION**

A diacromorph acritarch. Vesicle oval shape with simple, homomorphic, curved, slender processes which are evenly distributed bipolarly. Processes communicate with the vesicle and measure up to  $\frac{1}{2}$  -  $\frac{3}{4}$  of the vesicle diameter in length. There are faint longitudinal striations present on the vesicle. Surface of vesicle and processes is psilate. No excystment mechanism is observed.

**REMARKS**

The total number of processes (Pn) is only clearly seen and counted on one specimen.

**DIMENSIONS**

Vl: 16-30 $\mu\text{m}$	Vw: 10-19 $\mu\text{m}$	Pl: 5-16 $\mu\text{m}$	Pw: 0.25-2 $\mu\text{m}$	Pn: 12 each pole.	Sm: 4
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**PREVIOUS OCCURRENCES**

Late Ordovician, Eden Fm., U.S.A. (Loeblich and Tappan, 1978); Ashgill, Vaureal Fm., Canada (Jacobson and Achab, 1985); Late Ordovician, Libya (Molyneux and Paris, 1985; Molyneux, 1988).



**GENUS *Actipilion* Loeblich 1970a**

TYPE SPECIES: *Actipilion druggii* Loeblich 1970a

***Actipilion druggii* Loeblich 1970a**

Plate 1, fig. 2

*Actipilion druggii* Loeblich, 1970a, p. 711, fig. 3, a-e; Wright and Meyers, 1981, p. 19, pl. 3.

*Actipilion* aff. *A. druggii* (Loeblich), Martin, 1978, p. 79, pl. 12.1, fig. 3.

*Actipilion* cf. *A. druggii* (Loeblich), Molyneux, 1988, p. 45, pl. 8, fig. 3-6.

**DESCRIPTION**

Spherical to sub-spherical bi-layered vesicle having eight processes which arise from the outer wall layer. Processes do not communicate with the interior of the vesicle, but are separated by a thin wall layer. At the base of the process is a thick (2  $\mu\text{m}$ ) tire-like rim, similar to a plug only the centre is hollow. Processes are simple, homomorphic and cylindrical with an angular basal attachment to the vesicle; their tips are rounded to broadly acuminate. Processes are psilate, typically thin, flimsy, and wrinkled; their length is as long or longer than the vesicle diameter. The vesicle surface is shagrinose, with minor infilling of secondary pyrite. No excystment mechanism is observed.

**DIMENSIONS**

Vd: 44 $\mu$ m 50 $\mu$ m	Pl: 44 $\mu$ m 45 $\mu$ m	Pw: 6 $\mu$ m 7 $\mu$ m	Pn: 10 $\mu$ m 8 $\mu$ m	Sm: 2
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**PREVIOUS OCCURRENCES**

Ashgill, Sylvan Sh., U.S.A. (Loeblich, 1970a); Caradoc-Ashgill, Winterhouse Fm., Canada (Martin, 1978); Late Ordovician, Libya (Molyneux, 1988); Caradoc-Ashgill, Maquoketa Sh., U.S.A. (Wright and Meyers, 1981).

**GENUS *Ammonidium* Lister 1970**

TYPE SPECIES: *Baltisphaeridium microcladium* Downie 1963

***Ammonidium parvipinnatum* (Uutela and Tynni) comb. nov.**

Plate 1, fig. 3

*Multiplicisphaeridium parvipinnatum* Uutela and Tynni, 1991, p. 95, pl. XXI, fig. 217.

**DESCRIPTION**

A small spherical vesicle with numerous (ca. 50) evenly spaced conical homomorphic processes. Processes communicate with the vesicle interior; are of constant width and have only slightly curved proximal contacts; tips are expanded and furcated into six small pinnae (star shape), which can only be seen in light microscope as a bulbus tip. Processes are  $\frac{1}{4}$  of the vesicle diameter in length. The surfaces of the vesicle and processes are psilate. No excystment mechanism is observed.

**REMARKS**

*Ammonidium parvipinnatum* (Uutela and Tynni) comb. nov is similar to *Multiplicisphaeridium canadense* Staplin et al. 1965 in its description and measurements but differs in the number of furcated tips, *M. canadense* has two to four pinnae per process whereas *Ammonidium parvipinnatum* has six.

*Ammonidium* is differentiated from *Multiplicisphaeridium* in exhibiting only one order of process branching which arise from the extreme distal end of the process shaft and are of equal length.

**DIMENSIONS**

Vd: 12-20 $\mu\text{m}$	Pl: 2-3 $\mu\text{m}$	Pw: 0.25-0.5 $\mu\text{m}$	Pn: ~ 50	Sm: 25
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**PREVIOUS OCCURRENCES**

Middle Ordovician to Lower Silurian, Rapla Borehole, Estonia (Uutela and Tynni, 1991).

**GENUS *Axisphaeridium* Eisenack 1967**

TYPE SPECIES: *Axisphaeridium timofeevi* Eisenack 1967

***Axisphaeridium tricolumnelar* Uutela 1989**

Plate I, fig. 4

*Axisphaeridium tricolumnelar* Uutela, 1989, p. 22, pl. I, fig. 2; Uutela and Tynni, 1991, p. 33, pl. II, fig. 14.

**DESCRIPTION**

A thick (1µm) spherical to oval psilate vesicle, having numerous (ca. 100) overlapping, flimsy processes which are ¼ of the vesicle diameter in length. Processes arise from the outer wall layer and do not communicate with the vesicle interior. The processes are triangular and formed of three, thin echinate vela which taper to a pyramid shape. Excystment by means of a pylome which opens from within a thick high collar.

**REMARKS**

*Axisphaeridium tricolumnelar* is differentiated from *Polyancistrodorus columbariferus* in having triangular rather than quadratic processes.

**DIMENSIONS**

Vd: 30-56 µm	Pl: 3-10 µm	Pw: 1-3 µm	Sm: 12
pylome dia: 7.5 µm	collar height: 3 µm		collar thickness: 1 µm

**PREVIOUS OCCURRENCES**

Middle-Late Ordovician; Ralpa Borehole, Estonia (Uutela and Tynni, 1991).

**GENUS *Bacisphaeridium* Eisenack 1962**

TYPE SPECIES: *Bacisphaeridium bacifer* (Eisenack 1934) Eisenack 1962

***Bacisphaeridium* sp.**

Plate 1, fig. 5, 6

**DESCRIPTION**

Sub-spherical, thin ( $>0.5 \mu\text{m}$ ) vesicle. One hollow process, which has an acuminate distal tip, arises from and is in direct communication with the vesicle. The vesicle-process contact is curved. Both vesicle and process surfaces are covered with evenly spaced solid ( $0.5 \mu\text{m}$  high) echinae. Process length is  $\frac{2}{3}$  that of the vesicle diameter. No excystment mechanism is observed.

**DIMENSIONS**

Vd: $37 \mu\text{m}$	Pl: $23 \mu\text{m}$	Pw: $5 \mu\text{m}$	Pn: 1	Sm: 1
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**GENUS *Baltisphaeridium* (Eisenack 1958) Eisenack 1959**

TYPE SPECIES: *Baltisphaeridium longispinosum* (Eisenack 1931) ex. (Wetzel 1933)

Eisenack 1959

***Baltisphaeridium accinctum* Loeblich and Tappan 1978**

Plate 1, fig. 7, 8

*Baltisphaeridium accinctum* Loeblich and Tappan, 1978, p. 1246-47, pl. 4, figs. 1-3;  
Jacobson and Achab, 1985, p. 172, pl. 2, fig. 1; Uutela and Tynni, 1991, p. 35, pl. II, fig. 16.

*Baltisphaeridium dasos* Colbath, 1979, p. 11, pl. 3, fig. 6-8; Uutela and Tynni, 1991,  
p. 38, pl. IV, fig. 33.

*Baltisphaeridium* sp. B Wright and Meyers, 1981, p. 22, pl. 5, figs. A, B, C.

**DESCRIPTION**

A thick (1  $\mu\text{m}$ ) spherical vesicle having numerous simple, homomorphic, rigid processes that arise in a regular manner from the outer wall layer. The vesicle-process contact is angular. Processes are  $\frac{1}{3}$  of the vesicle diameter in length; hollow with evexate to acuminate distal tips. Surfaces of the vesicle and processes are ornamented with spinules. Separation of the vesicle and processes is by a proximal plug. No excystment mechanism is observed.

**DIMENSIONS**

Vd: 38-60 $\mu\text{m}$	Pl: 10-16 $\mu\text{m}$	Pw: 1-2.5 $\mu\text{m}$	Pn: ca. 50-100?	Sm: 13
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## PREVIOUS OCCURRENCES

Ashgill, Vaureal Fm., Canada (Jacobson and Achab, 1985); Middle Ordovician, Bromide Fm., U.S.A. (Loeblich and Tappan, 1978); Late Ordovician, Eden Sh., U.S.A. (Colbath, 1979); Caradoc- Ashgill, Maquoketa, U.S.A. (Wright and Meyers, 1981); Middle-Late Ordovician, Rapla Borehole, Estonia (Uutela and Tynni, 1991).

### *Baltisphaeridium aspersilumiferum* Loeblich and Tappan 1978

Plate 2, fig. 1

*Baltisphaeridium aspersilumiferum* Loeblich and Tappan, 1978, p. 1247-1248, pl. 4, figs.4-6.

## DESCRIPTION

A thick (1µm) spherical vesicle, with evenly spaced processes. Processes do not communicate with the vesicle interior and are separated with a proximal plug. Plug height is approximately 3 µm when measured on one specimen. Processes are homomorphic, conical to cylindrical in shape; they have an angular basal attachment to the vesicle and terminate with acuminate distal tips. Processes are ornamented by coarse granules up to 1 µm in length; the vesicle is psilate. Processes, numbering around 30, are typically  $\frac{1}{2}$ - $\frac{3}{4}$  the vesicle diameter in length. No excystment mechanism is observed.

## DIMENSIONS

Vd: 38-50 µm	Pl: 12-20 µm	Pw: 1-2.5 µm	Pn: 30-45 µm	Sm: 4
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**PREVIOUS OCCURRENCES**

Late Ordovician, Sylvan Sh., U.S.A. (Loeblich and Tappan, 1978).

***Baltisphaeridium brevifilicum* Kjellström 1971a**

Plate 2, fig. 2

*Baltisphaeridium brevifilicum* Kjellström, 1971a, p. 18, pl. 1, fig. 2; Uutela 1989, p.23, pl. 1, fig.3.

**DESCRIPTION**

A spherical vesicle with numerous (ca. 100) cylindrical homomorphic processes. Processes have acuminate to evexate distal terminations with angular proximal contacts and do not appear to communicate with the interior of the vesicle. Processes are  $\frac{1}{4}$  the vesicle diameter in length. Both the vesicle and processes are psilate. No excystment mechanism is observed.

**DIMENSIONS**

Vd: 33-57 $\mu\text{m}$	Pl: 5-12 $\mu\text{m}$	Pw: 0.5-1.5 $\mu\text{m}$	Pn: 50-200	Sm: 17
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**PREVIOUS OCCURRENCES**

Middle Ordovician, Borehole No. 1, Gotland (Kjellström, 1971a). Ordovician, Erratics southwestern Finland (Uutela, 1989)

***Baltisphaeridium filosum* Kjellström 1971a**

Plate 2, fig. 3

*Baltisphaeridium filosum* Kjellström, 1971a, p. 24; pl. 1, fig. 9; \*Uutela and Tynni, 1991, p. 39, pl. IV, fig. 37.

*Baltisphaeridium* cf. *B. filosum* (Kjellström) Turner, 1984, p. 97, pl. 6, fig. 4, 5.

**DESCRIPTION**

Spherical vesicle with numerous (ca. 40) cylindrical, homomorphic, flagelliform processes which typically overlap and are of equal length. Processes do not appear to communicate with the vesicle interior and join it by angular proximal contact; distal tips are acuminate. Processes are  $\frac{1}{3}$  the vesicle diameter in length. Vesicle and process surfaces are psilate to shagrinate. No excystment mechanism is observed, although this species typically has a split wall.

**REMARKS**

Although this species seems highly variable in size, the majority of the specimens are greater than 20  $\mu\text{m}$ . The original diagnosis of Kjellström (1971a) has *B. filosum* with a proportionally larger vesicle of 61-84  $\mu\text{m}$ . In fluorescent light the processes appear solid, but this cannot be confirmed. If the processes are solid then this species would fall under the genus *Comasphaeridium* Staplin et al. 1965.

**DIMENSIONS**

Vd: 14-35 $\mu\text{m}$	Pl: 4-10 $\mu\text{m}$	Pw: 0.25-1 $\mu\text{m}$	Sm: 23
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**PREVIOUS OCCURENCES**

Middle Ordovician, Borehole No. 1, Gotland (Kjellström, 1971a); Caradoc, Caradoc type sect., England (Turner, 1984); Early to Middle Ordovician, Rapla Borehole, Estonia (Uutela and Tynni, 1991).

***Baltisphaeridium nanninum* Eisenack 1965b**

Plate 2, fig. 4

*Baltisphaeridium nanninum* Eisenack, 1965b, p. 260, pl. 22, fig. 6-8, Uutela and Tynni, 1991, p. 43; pl. VI, fig. 57; \*Kjellström, 1971a, p. 35, pl. 2, fig. 6.

**DESCRIPTION**

A spherical to sub-spherical shagrinate vesicle which is covered with numerous (ca. ~200) short, thin, homomorphic, hair-like processes. Processes are up to 4  $\mu\text{m}$  in length and do not appear to communicate with the interior of the vesicle but seem to arise from the outer wall layer. No excystment mechanism is observed, although a split or breakage is observed on plate 2, fig. 4.

**DIMENSIONS**

Vd: 25-59 $\mu\text{m}$	Pl: 2-4 $\mu\text{m}$	Pw: 0.25-1.6 $\mu\text{m}$	Pn: 25-200	Sm: 12
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**PREVIOUS OCCURRENCES**

Middle-Upper Ordovician, Rapla Borehole, Estonia (Uutela and Tynni, 1991). In addition Uutela and Tynni (1991) listed in their previous records, occurrences from Lower Ordovician to Lower Silurian, Sweden.

***Baltisphaeridium* sp.**

Plate 2, fig. 5

**DESCRIPTION**

Spherical vesicle with (ca. 15) simple, hollow, homomorphic, stiff processes that arise from the outer wall layer and do not communicate with the vesicle interior. Separation of the processes from the vesicle cavity is by a thin wall layer. Processes have an angular basal contact with the vesicle; they are relatively long and taper continuously toward an acuminate tip. Detached processes leave a ring-like scar on the surface of the vesicle. Processes are less than the vesicle diameter in length. The vesicle is psilate and the processes are shagrinose to microgranulate. No excystment mechanism is observed.

**DIMENSIONS**

Vd: 30-55 $\mu\text{m}$	Pl: 16-55 $\mu\text{m}$	Pw: 3-4 $\mu\text{m}$	Pn: 8-20	Sm: 7
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**GENUS *Baltisphaerosum* Turner 1984**

TYPE SPECIES: *Baltisphaerosum christoferi* (Kjellström 1976) Turner 1984

***Baltisphaerosum dispar* Turner 1984**

Plate 2, fig. 6

*Baltisphaerosum dispar* Turner, 1984, p. 103-104, pl. 3, fig. 3-4, 6-7.

**DESCRIPTION**

A 1  $\mu$ m thick spherical vesicle with (ca. 10) simple, hollow, homomorphic, processes that arise from the outer wall layer and do not communicate with the vesicle interior. Separation of the processes from the vesicle is with a U-shaped proximal plug. Processes, have a slightly constricted, angular basal contact with the vesicle, are cylindrical, and taper continuously toward an evexate or acuminate tip. Processes are less than vesicle diameter in length. The vesicle is shagrinose and the processes are granular. No excystment mechanism is observed.

**DIMENSIONS**

Vd: 52-61 $\mu$ m	Pl: 33-44 $\mu$ m	Pw: 4-6 $\mu$ m	Pn: 7-14	Sm: 5
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**PREVIOUS OCCURRENCES**

Caradoc, Caradoc type sect., England (Turner, 1984)

**GENUS *Cheleutochroa* (Loeblich and Tappan 1978) emend. Turner 1984**

TYPE SPECIES: *Cheleutochroa gymnobrachiata* Loeblich and Tappan 1978

***Cheleutochroa diaphorosa* Turner 1984**

Plate 3, fig. 1

*Cheleutochroa diaphorosa* Turner, 1984, p. 105, pl. 1, fig. 5, pl. 7, fig. 3.

*Cheleutochroa* sp. cf. *C. gymnobrachiata* Wright and Meyers, 1981, p. 23, pl. 5, figs.

E, G, H, I.

**DESCRIPTION**

A spherical to sub-spherical vesicle with numerous (ca. 30) hollow processes. Species are heteromorphic containing both simple and bifurcated (rarely trifurcated) processes. Processes are conical with acuminate distal terminations; their curved proximal contacts are in close proximity to each other. The processes communicate with the interior of the vesicle and their proximal contacts have radial striae which extend onto the surface of the vesicle; the processes themselves are psilate. Processes are of various lengths, all of which are less than the diameter of the vesicle. No excystment mechanism is observed.

**REMARKS**

*Cheleutochroa* is differentiated from *Multiplicisphaeridium* by having radial striae originating at the process and continuing on the surface of the vesicle.

**DIMENSIONS**

Vd: 19 $\mu\text{m}$ 25 $\mu\text{m}$	Pl: 6 $\mu\text{m}$ 7 $\mu\text{m}$	Pw: 3 $\mu\text{m}$ 4 $\mu\text{m}$	Sm: 2
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**PREVIOUS OCCURRENCES**

Caradoc-Ashgill, Maquoketa Sh., U.S.A. (Wright and Meyers, 1981); Caradoc, Caradoc type sect., England (Turner, 1984).

*Cheleutochroa* sp.

Plate 3, fig. 2, 3

**DESCRIPTION**

The distinctly spherical vesicle has numerous (ca. 50) heteromorphic processes. Processes on the vesicle are of varying lengths and widths, with up to three orders of furcation. The hollow, psilate processes are in direct communication with the interior of the vesicle; their length is  $< \frac{1}{2}$  of the vesicle diameter. Processes have acuminate distal terminations and curved proximal contacts with the vesicle. Pronounced radial striations extending from the curved proximal contact and to the surface of the vesicle. No excystment mechanism is observed.

**REMARKS**

*Cheleutochroa* sp. is differentiated from *Cheleutochroa diaphorosa* in having processes that have three orders of furcation.

**DIMENSIONS**

Vd: 15-21 $\mu\text{m}$	Pl: 2.5-7 $\mu\text{m}$	Pw: 1-3 $\mu\text{m}$	Sm: 3
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**GENUS *Comasphaeridium* Staplin et al. 1965**

TYPE SPECIES: *Comasphaeridium cometes* (Valensi 1949) Staplin et al. 1965

***Comasphaeridium lanugiferum* Jacobson and Achab 1985**

Plate 3, fig. 4, 5

*Comasphaeridium lanugiferum* Jacobson and Achab, 1985, p. 176, pl. 5, figs. 6-8.

**DESCRIPTION**

A thin ( $< 0.5 \mu\text{m}$ ) spherical to sub-spherical vesicle with minor folds. The vesicle is densely covered with solid filiform processes. The processes, though quite dense, are evenly spaced around the vesicle perimeter where they are separated and can be easily identified. No excystment mechanism is observed.

**DIMENSIONS**

Vd: 30 and 34 $\mu\text{m}$	Pl: 2 $\mu\text{m}$	Pw: 0.25 $\mu\text{m}$	Pn: ca. 100's	Sm: 2
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**PREVIOUS OCCURRENCES**

Ashgill, Vaureal Fm., Canada (Jacobson and Achab, 1985).



***Comasphaeridium varispinosum* Uutela 1989**

Plate 3, fig. 6

*Comasphaeridium varispinosum* Uutela, 1989, p. 27, pl. III, fig. 24.

**DESCRIPTION**

The small spherical vesicle is totally covered with a dense mat of flagelliform processes which are of variable lengths and widths (see dimensions). The nature of the process-vesicle contact or whether the processes communicate with the vesicle interior is uncertain; processes are both acuminate and bulbous at their distal tips; processes do expand distally towards the vesicle and may at times join each other at their base. Processes are psilate in nature. No excystment mechanism is observed.

**DIMENSIONS**

Vd: 15 $\mu\text{m}$	Pl: 1-8 $\mu\text{m}$	Pw: 0.25-1 $\mu\text{m}$	Sm: 1
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**PREVIOUS OCCURRENCES**

Middle Ordovician erratics, Finland (Uutela, 1989).

***Comasphaeridium* sp. A**

Plate 3, fig. 7

**DESCRIPTION**

This is a small sub-spherical species. Vesicle is totally covered by a dense covering of thin, cylindrical, psilate processes which are of various lengths. The shape of the vesicle, the process-vesicle contact or whether the processes communicate with the vesicle interior is uncertain; processes are both acuminate and bulbous at their distal tips; processes appear to join distally. No excystment mechanism is observed.

**DIMENSIONS**

Vd: 22.6 $\mu\text{m}$	Pl: 3-12 $\mu\text{m}$	Pw: 0.25 $\mu\text{m}$	Sm: 1
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***Comasphaeridium* sp. B**

Plate 3, fig. 8

**DESCRIPTION**

A small sub-spherical species. Vesicle is totally covered by a dense covering of cylindrical, psilate processes which are of various lengths and widths. The shape of the vesicle, the process-vesicle contact or whether the processes communicate with the vesicle interior is uncertain; processes have truncated or bulbous distal tips; processes appear to join distally. No excystment mechanism is observed.

**DIMENSIONS**

Vd: 19 µm	Pl: 1-16 µm	Pw: 0.5-2.5 µm	Sm: 1
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**REMARKS**

In light microscopy *Comasphaeridium varispinosum*, *Comasphaeridium* sp. A and *Comasphaeridium* sp. B could not be described because of their transparent colour and dense process cover. They are only seen and counted using fluorescence microscopy. Only with the SEM is the morphology of these species described. The distinguishing feature that separates these three species is the apparent differences in their processes. *C. varispinosum* has flagelliform processes that expand or thicken toward the base; *Comasphaeridium* sp. A has thinner uniform hair like processes of variable lengths; *Comasphaeridium* sp. B has both thick and thin cylindrical processes with capitate tips.

**?*Comasphaeridium* sp. C**

Plate 4, fig. 1, 2, 3

**DESCRIPTION**

A spherical body, margins irregular, apparently single walled. The outer wall layer appears as a mass of solid cylindrical hooklike processes that extend approximately 2 µm beyond the vesicle perimeter and are 0.25 µm thick. These cylindrical loops may terminate with bulbous tips, which hook back towards the vesicle or may loop back to join each other. Excystment mechanism is through a circular pylome.

**REMARKS**

This species possesses an ornament of cylindrical hooklike processes on the outer wall layer and therein is differentiated from other *Comasphaeridium* ssp. A pylome is only seen and measured on one specimen as a result this species is questionably placed under the genus *Comasphaeridium*.

**DIMENSIONS**

Vd: 25-46 $\mu\text{m}$	Sm: 10	Pylome: 10 $\mu\text{m}$
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**GENUS *Dicommopalla* Loeblich 1970b**

TYPE SPECIES: *Dicommopalla macadamii* Loeblich 1970b

***Dicommopalla macadamii* Loeblich 1970b**

Plate 4, fig. 4, 5

*Dicommopalla macadamii* Loeblich, 1970b, p. 39, fig. 1-12; Jacobson, 1978b, p. 125, pl. II, fig. 4-11; Colbath, 1979, p. 14, pl. 4, figs. 6,7; Legault, 1982, p. 1852, pl. 1, fig. 13; Uutela, 1989, p. 28, pl. IV, fig. 27; Uutela and Tynni, 1991, p. 59, pl. X, fig. 117.

**DESCRIPTION**

Spherical vesicle doubled walled. The outer margin, or keel, is defined by an outer wall cover which is typically flimsy and ragged, although well preserved. This outer wall layer extends beyond the vesicle perimeter approximately 2  $\mu\text{m}$ . Excystment is through a circular pylome, its collar is flat and smooth, its operculum is punctate.

**DIMENSIONS**

Vd: 26-90 $\mu\text{m}$	Operculum: ID= 7-10 $\mu\text{m}$ , OD= 8-10 $\mu\text{m}$	Sm: 8
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**PREVIOUS OCCURRENCES**

Late Ordovician, Dillsboro Fm., U.S.A. (Loeblich, 1970b); Edenian-Maysvillian, Clay's Ferry Fm., U.S.A. (Jacobson, 1978); Caradoc-Ashgill, Eden Fm., U.S.A. (Colbath, 1979); Ashgill, Orphan Knoll, Canada (Legault, 1982); Ordovician, Rapla Borehole, Estonia (Uutela and

Tynni, 1991).

**GENUS *Excultibrachium* (Loeblich and Tappan 1978) emend. Turner 1984**

TYPE SPECIES: *Excultibrachium concinnum* Loeblich and Tappan 1978

***Excultibrachium concinnum* Loeblich and Tappan 1978**

Plate 4, fig. 6; Plate 5, fig. 1

*Excultibrachium concinnum* Loeblich and Tappan, 1978, p. 1267, pl. 3-6.

*Ordovicidium gracile* Colbath, 1979 p. 23, pl. 8, figs. 4-7.

**DESCRIPTION**

The spherical vesicle has thin cylindrical processes which arise from the outer layer of the vesicle; processes form an angular contact with the vesicle and do not communicate with the vesicle interior; distal tips branch into four or more pinnulae. The pinnulae tips are flexible and taper into long hair-like extensions of various lengths which drape back towards and onto the vesicle. The processes are slightly greater than  $\frac{1}{4}$  vesicle diameter in length. Both vesicle and processes are psilate. No excystment mechanism is observed.

**REMARKS**

Both Loeblich and Tappan (1978) and Colbath (1979) describe this species processes as having proximal plugs, This feature was not observed in the Winterhouse specimens.

**DIMENSIONS**

Vd: 38-55 $\mu\text{m}$	Pl: 6-18 $\mu\text{m}$	Pw: 1-3 $\mu\text{m}$	Pn: 30-50 $\mu\text{m}$	Sm: 10
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**PREVIOUS OCCURRENCES**

Late Ordovician, Eden Fm., U.S.A. (Loeblich and Tappan, 1978; Colbath, 1979).

**GENUS *Gloeocapsomorpha* (Zalessky 1917) emend. Foster et al. 1989**

TYPE SPECIES (by monotypy): *Gloeocapsomorpha prisca* Zalessky 1917

***Gloeocapsomorpha* sp.**

Plate 5, fig. 2, 3

**DESCRIPTION**

Circular to irregularly-shaped globular colonies of several cells. Individual cells are typically shagrinate and pitted. No excystment mechanism is observed.

**REMARKS**

Size and shape of *Gloeocapsomorpha* sp. is highly variable within the Winterhouse Formation samples. All occurrences, whether one cell or several, were counted as one.

**PREVIOUS OCCURRENCES**

Ordovician sequences in the Baltic, Australia, Canada and U.S.A. (Wicander et al., 1996).

**GENUS *Gorgonisphaeridium* Staplin et al. 1965**

TYPE SPECIES: *Gorgonisphaeridium winslowiae* Staplin et al. 1965

***Gorgonisphaeridium* sp. A**

Plate 5, fig. 4, 5

**DESCRIPTION**

Subspherical to elongate shagrinate vesicle ornamented with numerous (ca. 100's) evenly distributed, short, stout, homomorphic tubercles which are columnar in appearance. These solid tubercles are expanded at their distal extremity where they are capitate to slightly furcated. Furcation may be more than once. No obvious excystment mechanism is observed.

**DIMENSIONS**

Vd: 30-35 $\mu\text{m}$	Pl: 0.75-1.6 $\mu\text{m}$	Pw: 0.25-0.5 $\mu\text{m}$	Sm: 3
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***Gorgonisphaeridium* sp. B**

Plate 5, fig. 6, 7

**DESCRIPTION**

Thin, 0.25µm thick, spherical to sub-spherical shagrinated vesicle ornamented with numerous short heteromorphic processes. These processes are of various shapes, although their lengths appear constant. The processes may furcate at any place along their length. The tips may furcate; or the stem itself may furcate as it joins the vesicle wall in a root like manner. These features are only visible under SEM. Excystment is by a splitting of the cell wall.

**REMARKS**

*Gorgonisphaeridium* sp. A is distinguished from *Gorgonisphaeridium* sp. B by its elongated vesicle shape and its homomorphic tubercles with capitate to slightly furcated tips.

*Gorgonisphaeridium* Staplin et al. 1965 is distinguished from *Comasphaeridium* Staplin et al. 1965 in that its solid tubercles are expanded or branched.

**DIMENSIONS**

Vd: 24-46 µm	Pl: 0.75-2.5 µm	Pw: 0.25-1.6 µm	Sm: 5
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GENUS *Leiofusa* (Eisenack 1938) emend. (Eisenack 1965a) emend. Combaz et al 1967

TYPE SPECIES: *Leiofusa fusiformis* (Eisenack 1934) ex Eisenack 1938

***Leiofusa fusiformis* (Eisenack 1934) ex Eisenack 1938**

Plate 5, fig. 8

*Leiofusa fusiformis* Eisenack, 1938a, p. 65-66, pl.4, fig. 9; \*Cramer, 1970, p. 71, 72, pl. 2, fig. 35; Jacobson and Achab, 1985, p. 183, pl. 5, figs. 9, 10.

**DESCRIPTION**

A hollow fusiform cyst with two simple processes at the poles. The central vesicle appears asymmetrical, one side is slightly convex the other being broadly convex. Processes are in direct communication with the vesicle interior and are easily distinguished from it; their lengths are  $\frac{1}{2}$  that of the vesicle length. Vesicle and process surfaces are psilate and wrinkled. The thickness of the fusiform is  $< 0.5 \mu\text{m}$ . No excystment mechanism is observed.

**REMARKS**

This species is distinguished from *Leiofusa asymmetrica* Colbath 1979 by its psilate wrinkled surface, *L. asymmetrica* has irregular spaced grana on its surface.

**DIMENSIONS**

Vl: 82 $\mu\text{m}$	Vw: 19 $\mu\text{m}$	Sm: 1
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**PREVIOUS OCCURRENCES**

Ordovician, Baltic region (Eisenack 1938a); Ashgill, Vaureal Fm., Canada (Jacobson and Achab, 1985).

**GENUS *Lophosphaeridium* (Timofeev 1959) ex (Downie 1963) emend. Lister 1970**

TYPE SPECIES: *Lophosphaeridium rarum* Timofeev (1959) ex. Downie 1963

***Lophosphaeridium aequicuspidatum* Playford and Martin 1984**

Plate 6, fig. 1

*Lophosphaeridium aequicuspidatum* Playford and Martin, 1984, p. 202; pl. 7, fig.

H-K; Uutela and Tynni, 1991, p. 77, pl. XVII, fig.4.

**DESCRIPTION**

A psilate, spherical vesicle ornamented with numerous (ca. 100's) simple echinate spines. Spines vary in size from 0.5  $\mu\text{m}$  up to 3  $\mu\text{m}$  in width and height. They join the vesicle with a curved proximal contact and terminate with an acuminate tip. Spines appear solid. No excystment mechanism is observed although one specimen did show a partial splitting of the vesicle wall.

**REMARKS**

This species shows considerable variation in size.

**DIMENSIONS**

Vd: 12-35 $\mu\text{m}$	Pl. 0.5-3 $\mu\text{m}$	Sm: 50
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**PREVIOUS OCCURRENCES**

Middle Ordovician, Rapla Borehole, Estonia (Uutela and Tynni, 1991); Early-Middle Ordovician, Canning Basin, Australia (Playford and Martin, 1984).

***Lophosphaeridium edenense* Loeblich and Tappan 1978**

Plate 6, fig. 2

*Lophosphaeridium edenense* Loeblich and Tappan, 1978, p. 1272-1275, pl. 14, figs. 4-5; Jacobson and Achab, 1985, p. 184, pl. 3, fig. 6.

**DESCRIPTION**

Thick (0.5-1  $\mu\text{m}$ ) spherical vesicle ornamented with a dense but evenly spaced cover of solid grana. Grana are rounded and measure up to 0.6  $\mu\text{m}$  in diameter and height. Vesicle typically folded, no excystment mechanism observed.

**DIMENSIONS**

Vd: 22-33 $\mu\text{m}$	Sm: 10
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**PREVIOUS OCCURRENCES**

Caradoc, Eden Fm., U.S.A. (Loeblich and Tappan, 1978); Ashgill, Vaureal Fm., Canada (Jacobson and Achab, 1985).

***Lophosphaeridium papillatum* (Staplin) Martin 1969**

Plate 6, fig. 3

*Protoleiosphaeridium papillatum* Staplin, 1961, pp. 406-407, pl. 48, figs. 10-11.

*Lophosphaeridium papillatum* (Staplin) Martin, 1969, p. 111-112; Uutela and Tynni, 1991, p. 79, pl. XV11, fig. 168.

**DESCRIPTION**

Thick (1  $\mu\text{m}$ ), psilate, spherical vesicle covered with heteromorphic solid grana of various size and spacing. Their size ranges from 0.2-1  $\mu\text{m}$ , some are conical shape with acuminate tips while others are more tubular with capitate tips. No excystment mechanism observed.

**DIMENSIONS**

Vd: 15-40 $\mu\text{m}$	Sm: 11
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**PREVIOUS OCCURRENCE**

Devonian, Duvernay member, Canada (Staplin, 1961); Ordovician, Rapla Borehole, Estonia (Uutela and Tynni, 1991).

***Lophosphaeridium papulatum* Martin 1983**

Plate 6, fig. 4

*Lophosphaeridium papulatum* Martin, 1983, p. 23; pl. 10, fig. 17.**DESCRIPTION**

Thick (1  $\mu\text{m}$ ) spherical vesicle ornamented with a dense cover of solid grana. Grana have variable spacing, may fuse to form larger verrucae giving the vesicle a knobby appearance. Grana (1-2  $\mu\text{m}$  in diameter and height) are evexate to well rounded, and give the vesicle a serrated margin. No excystment mechanism is observed.

**DIMENSIONS**

Vd: 20-35 $\mu\text{m}$	Sm: 8
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**PREVIOUS OCCURRENCES**

Early Ordovician, Rockcliffe Fm., Canada (Martin, 1983).

**GENUS *Lunulidia* Eisenack 1958b**

TYPE SPECIES: *Lunulidia lumula* (Eisenack 1951) Eisenack 1958b

***Lunulidia* sp. A**

Plate 6, fig. 5

**DESCRIPTION**

A thin  $<0.5\ \mu\text{m}$  crescent shaped vesicle with pointed tips. Vesicle is hollow and its surface is shagrinata-granulate. No apparent excystment mechanism.

**DIMENSIONS**

Vesicle length between tips: 72 $\mu\text{m}$	Vesicle widest dimension central area: 22 $\mu\text{m}$	Sm: 1
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***Lunulidia* sp. B**

Plate 6, fig. 6

**DESCRIPTION**

A thin,  $<0.5\ \mu\text{m}$  thick, crescent shaped vesicle with rounded tips. Vesicle is hollow, wrinkled and its surface is shagrinose to granulate. No apparent excystment mechanism.

**REMARKS**

This species differs from *Lunulidia* sp. A in being longer and having rounded tips. It has the same shape as *Lunulidia lunula* Eisenack 1958 but at  $154\ \mu\text{m}$  is much smaller (*L. lunula* is  $770\ \mu\text{m}$ ). In addition *L. lunula* appears to be psilate whereas *Lunulidia* sp. B is granulate.

**DIMENSIONS**

Vesicle length between tips: $154\ \mu\text{m}$	Vesicle widest dimension central area: $18\ \mu\text{m}$	Sm: 1
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**GENUS *Micrhystridium* (Deflandre 1937b) emend. (Staplin 1961) emend. Lister 1970**

TYPE SPECIES: *Micrhystridium inconspicuum* (Deflandre 1935) Deflandre 1937

***Micrhystridium acuminosum* Cramer and Díez 1977**

Plate 7, fig. 1

*Micrhystridium acuminosum* Cramer and Díez, 1977, p. 347, pl. 1, fig. 3-4; Uutela and Tynni, 1991, p. 80, pl. XVIII, fig. 171.

**DESCRIPTION**

A polygonal vesicle with several conical homomorphic processes arranged in a star like manner. Processes, which communicate with the interior of the vesicle, are extremely broad based with acuminate distal terminations. Processes vary in length from  $\frac{1}{8}$  up to  $\frac{3}{4}$  of the vesicle diameter. Both vesicle and processes are shagrinate to microgranular. No excystment mechanism observed.

**DIMENSIONS**

Vd: 8-22 $\mu\text{m}$	Pl: 3-14 $\mu\text{m}$	Pw: 1.5-7 $\mu\text{m}$	Pn: 6-24	Sm: 7
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**REMARKS**

The specimens found in the Winterhouse are smaller than those of the original diagnosis.

Vesicle diameter is 32-38  $\mu\text{m}$  in the original diagnosis of Cramer and Díez (1977).

**PREVIOUS OCCURRENCES**

Late Arenigian, Morocco (Cramer and Díez, 1977); Middle Ordovician, Rapla Borehole, Estonia (Uutela and Tynni, 1991).

***Micrhystridium aremoricum* (Paris and Deunff) emend. Fensome et al. 1990**

Plate 7, fig. 2

*Micrhystridium inconspicuum aremoricum* Paris and Deunff, 1970, p. 32, pl. 2, fig. 20; Uutela and Tynni, 1991, p. 82, pl. XIX, fig. 186.

*Micrhystridium aremoricum* (Paris and Deunff) emend. Fensome et al., 1990, p. 323.

**DESCRIPTION**

A small, spherical to polygonal vesicle with numerous (ca. 50) simple processes. Processes are in communication with the vesicle interior, have expanded distal bases and acuminate tips. Processes are typically simple but rarely one or two may bifurcate. Spacing of the processes is greater towards the centre of the vesicle while those at the perimeter (compressional view) are numerous and overlap. Processes are less than the vesicle diameter in length. Both vesicle and processes are psilate to shagrinate. No excystment mechanism is observed.

**DIMENSIONS**

Vd: 9-18 $\mu\text{m}$	Pl: 3-4 $\mu\text{m}$	Pw: 2	Sm: 5
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**PREVIOUS OCCURRENCES**

Middle Ordovician, Rapla Borehole, Estonia (Uutela and Tynni, 1991). In addition Uutela and Tynni (1991) listed in their previous records occurrences from Caradoc, Caradoc type sect., Britain (Turner, 1984); Ordovician, Baltic erratics, Finland (Uutella, 1989).

***Micrhystridium equispinosum* Turner 1984**

Plate 7, fig. 3

*Micrhystridium equispinosum* Turner, 1984, p. 119-120, pl. 15, fig. 1; Uutela and Tynni, 1991, p. 81, pl. XVII, fig. 173.

**DESCRIPTION**

A sub-spherical to polygonal vesicle with numerous (ca. 25) thin, flagelliforme, homomorphic processes which are the same length or slightly longer than the vesicle diameter. Processes are in direct communication with the vesicle interior. The surfaces of the processes and vesicle are psilate. No excystment mechanism is observed.

**DIMENSIONS**

Vd: 7-22 $\mu\text{m}$	Pl: 7-18 $\mu\text{m}$	Pw: 0.25-1 $\mu\text{m}$	Pn: 10-22	Sm: 15
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**PREVIOUS OCCURRENCES**

Caradoc, Caradoc type sect., Britain (Turner, 1984); Middle to Late Ordovician, Rapla Borehole, Estonia (Uutela and Tynni, 1991).

***Micrhystridium fragile* Deflandre 1947**

Plate 7, fig. 4

*Micrhystridium fragile* Deflandre, 1947, p. 921, pl. 8, fig. 13-18; Cramer, 1970, p. 101-102, fig. 28; Uutela and Tynni, 1991, p. 82, pl. XVII, fig. 175.

**DESCRIPTION**

Spherical vesicle with less than 20 thin (0.25  $\mu\text{m}$ ), hair-like, simple, cylindrical, homomorphic processes. Processes are barely identifiable; basal contact with the vesicle is angular, distal tips are acuminate. Processes are in direct communication with the vesicle interior and are  $\frac{1}{2}$  the vesicle diameter in length. Vesicle and process surfaces are psilate. No excystment mechanism is observed.

**DIMENSIONS**

Vd: 7-15 $\mu\text{m}$	Pl: 4-10 $\mu\text{m}$	Pw: 0.25 $\mu\text{m}$	Pn: 12-16	Sm: 10
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**PREVIOUS OCCURRENCES**

Middle-Late Ordovician, Rapla Borehole, Estonia (Uutela and Tynni, 1991). In addition Uutela and Tynni (1991) have listed occurrences from the Middle Ordovician to Silurian, Belgium, (Martin 1966a, b; 1968); Devonian, Spain (Cramer, 1964); Jurassic, France (Deflandre, 1947).

***Micrhystridium shinetonense* Downie 1958**

Plate 7, fig. 5

*Micrhystridium shinetonense* Downie, 1958, p. 342, fig. 5a-g; Uutela and Tynni, 1991, p.85: pl. XIX, fig. 189

**DESCRIPTION**

Small subspherical to polygonal vesicle with numerous (ca. 40) simple, flagelliforme, homomorphic processes which typically overlap and may vary in length. Processes are in direct communication with the vesicle interior and join by a curved proximal contact; distal tips are acuminate. Processes are  $\frac{1}{3}$  the vesicle diameter in length. Vesicle and process surfaces are psilate to shagrinate. No excystment mechanism observed.

**DIMENSIONS**

Vd: 12-22 $\mu\text{m}$	Pl: 4-8 $\mu\text{m}$	Pw: 0.25-1.5 $\mu\text{m}$	Sm: 14
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**PREVIOUS OCCURRENCES**

Middle to Late Ordovician, Rapla Borehole, Estonia (Uutela and Tynni, 1991). Tremadoc, Shineton Shales, U.K. (Downie, 1958). In addition Uutela and Tynni (1991) listed occurrences from Ordovician and Silurian deposits in Europe.

***Micrhystridium* sp. A**

Plate 7, fig. 6

**DESCRIPTION**

Small spherical vesicle having simple, conical, rigid, homomorphic processes that vary in length. Processes are in direct communication with the vesicle interior and joined by a curved proximal contact; distal tips are acuminate. Processes are up to  $\frac{1}{4}$  the vesicle diameter in length. Vesicle and process surfaces are psilate. No excystment mechanism is observed.

**DIMENSIONS**

Vd: 15-20 $\mu\text{m}$	Pl: 3-8 $\mu\text{m}$	Pw: 1-2.5 $\mu\text{m}$	Pn: 14-28	Sm: 5
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***Micrhystridium* sp. B**

Plate 7, fig. 7, 8

**DESCRIPTION**

A distinctly spherical vesicle with conical, heteromorphic processes. Processes are simple with broad acuminate distal tips, one or two processes may bifurcate. The processes, with their broad base, communicate with the vesicle interior and are  $\frac{1}{2}$  the vesicle diameter in length. Vesicle and process surfaces are psilate. No excystment mechanism is observed.

**DIMENSIONS**

Vd: 15-20 $\mu\text{m}$	Pl: 3-14 $\mu\text{m}$	Pw: 0.5-4 $\mu\text{m}$	Pn: 8-25	Sm: 7
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***Micrhystridium* sp. C**

Plate 7, fig. 9

**DESCRIPTION**

Small polygonal vesicle having simple conical homomorphic processes that vary in length. Processes are in direct communication with the vesicle interior and join by a curved proximal contact; distal tips are acuminate. Processes are up to  $\frac{1}{2}$  the vesicle diameter in length. Vesicle and process surfaces are psilate. No excystment mechanism is observed.

**REMARKS**

This species is distinguished from species A and B by its polygonal vesicle shape and the smaller process width. Species A is distinguished from species B in having shorter non furcated processes.

*Micrhystridium* is distinguished from *Polygonium* and *Goniosphaeridium* by its relatively small vesicle size ( $< 20 \mu\text{m}$ , rarely  $> 27 \mu\text{m}$ ); and from *Veryhachium* by having a greater number of processes arising from the vesicle, whose shape is not modified by their position and number.

**DIMENSIONS**

Vd: 12-23 $\mu\text{m}$	Pl: 5-14 $\mu\text{m}$	Pw: 1-2 $\mu\text{m}$	Pn: 18-30	Sm: 20
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**GENUS *Moyeria* Thusu 1973**

TYPE SPECIES: *Moyeria uticaensis* Thusu 1973, by original designation.

***Moyeria cabottii* (Cramer) emend. Miller and Eames 1982**

Plate 8, fig. 1, 2, 3, 4, 5, 6

*Eupoikilofusa cabottii* Cramer, 1970, p. 87, pl. 4, figs. 66-67; \*Turner, 1984, p. 109, pl. 12, figs. 3, 6.

*Moyeria cabottii* (Cramer) Miller and Eames, 1982, p. 242, pl. 3, fig. 3.

**DESCRIPTION**

The vesicle is of two shapes, one spherical the other more rectangular. There are no processes on the vesicle; it is ornamented with about 20-25 spiral muri. These muri (0.5-1  $\mu\text{m}$  thick) form a helicoidal pattern appearing to radiate out from each pole of the longitudinal axis. In compressional view, where opposite walls are superimposed, these muri give a distinct cross-hatched pattern on the surface of the vesicle. Vesicle may show an outer membrane. The vesicle wall is 0.5  $\mu\text{m}$  thick and psilate. No excystment mechanism is observed.

**REMARKS**

There are two very distinct vesicle shapes, one spherical the other rectangular. The



rectangular shape species having a distinct outer membrane. The different shapes may be considered to represent different species, or a morphological variance of the same species. According to Miller and Eames (1982) this morphological variance is considered to be the result of compression. This author does not agree. See plate 8 for two very distinct vesicle shapes. The vesicle diameter (Vd) measurement is taken to be the longest dimension of the rectangular forms.

*Moyeria* has been differentiated from *Eupoikilofusa* by not having polar processes or longitudinal ornamentation.

#### **DIMENSIONS**

Vd: 23-57 $\mu\text{m}$	Sm: 16
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#### **PREVIOUS OCCURRENCES**

Caradoc, Caradoc type sect., England (Turner, 1984); Lower Llandovery, Medina Gr., U.S.A. (Miller and Eames, 1982); Silurian, (Cramer, 1970).

GENUS *Multiplicisphaeridium* (Staplin 1961) emend. (Staplin et al. 1965) emend.

(Eisenack 1969) emend. (Lister 1970) emend. Turner 1984

TYPE SPECIES: *Multiplicisphaeridium ramispinosum* Staplin 1961

***Multiplicisphaeridium irregulare* Staplin et al. 1965**

Plate 9, fig. 1

*Multiplicisphaeridium irregulare* Staplin et al., 1965, p. 183, pl. 18, figs. 17-18; Martin, 1980, p. 115, pl. 4, fig. 4; Wright and Meyers, 1981, p. 26, pl. 6, fig. D, F, H; Turner, 1984, p. 121, pl. 7, fig. 4; Uutela and Tynni, 1991, p. 93, pl. XXII, fig. 219.

**DESCRIPTION**

Subsphaerical thin vesicle with numerous (ca. 40) hollow heteromorphic processes that communicate directly with the vesicle interior. Both vesicle and processes are psilate to shagrinate; processes are approximately the same length, or  $\frac{3}{4}$  of the vesicle diameter. Processes are simple and bifurcated (rarely trifurcated), and branch in an irregular manner anywhere above the distal base. Simple and branching processes are conical, with expanded bases and acuminate tips. No excystment mechanism is observed.

**DIMENSIONS**

Vd: 16-23 $\mu\text{m}$	Pl: 6-12 $\mu\text{m}$	Pw: 2-4 $\mu\text{m}$	Pn: 20-23	Sm: 12
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**PREVIOUS OCCURRENCES**

Llandeilo-Caradoc, Canada (Staplin et al., 1965); Middle Ordovician to Lower Silurian, Rapla

Borehole, Estonia (Uutela and Tynni, 1991); Caradoc, Caradoc type sect., England (Turner, 1984); Caradoc-Ashgill, Maquoketa Sh., U.S.A. (Wright and Meyers, 1981); Late Ordovician, White Head Fm., Canada (Martin, 1980).

***Multiplicisphaeridium martae* Cramer and Díez 1972**

Plate 9, fig. 2

*Multiplicisphaeridium martae* Cramer and Díez, 1972, p. 42-43, pl. 1, figs. 5, 9, pl. 2, fig. 3; Uutela and Tynni, 1991, p. 93, pl. XXII, fig. 220.

**DESCRIPTION**

Spherical to polygonal shaped vesicle with numerous (ca. 50) conical processes. Processes have curved proximal contacts and the distal terminations, usually branching into two, or sometimes more, very short pinnae. Processes are  $\frac{1}{2}$  the vesicle diameter in length. The surface of the vesicle and processes are psilate to shagrinate. No excystment mechanism is observed.

**REMARKS**

*Multiplicisphaeridium* is differentiated from *Micrhystridium*, *Polygonium*, *Baltisphaeridium* and *Verhachium* by having processes that are distally furcated, and from *Ordoviciidium* by having processes that communicate with the vesicle interior.

**DIMENSIONS**

Vd: 16 $\mu\text{m}$	Pl: 7 $\mu\text{m}$	Pw: 2.5 $\mu\text{m}$	Sm: 1
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**PREVIOUS OCCURRENCES**

Lower Ordovician to Lower Silurian, Rapla Borehole, Estonia (Uutela and Tynni, 1991).

Middle Cambrian: Spain (Cramer and Díez, 1972).

***Multiplicisphaeridium* sp. A**

Plate 9, fig. 3

**DESCRIPTION**

Small sub-spherical vesicle with numerous short heteromorphic processes that communicate directly with the vesicle interior. Processes are both simple, and distally furcate with two or three branches. Processes are  $\frac{1}{4}$  of the vesicle diameter in length, are broad based and have a curved proximal contact with the vesicle. Both vesicle and processes are psilate to shagrinate. No excystment mechanism is observed.

**DIMENSIONS**

Vd: 15-22 $\mu\text{m}$	Pl: 4-5 $\mu\text{m}$	Pw: 1-2 $\mu\text{m}$	Pn: ~35	Sm: 3
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***Multiplicisphaeridium* sp. B**

Plate 9, fig. 4, 5

**DESCRIPTION**

A small polygonal-trapezoidal (?) vesicle having straight sides with less than 10 heteromorphic processes. Processes are of a variety of lengths from 25% to 100% of the vesicle diameter. Process tips are well rounded. Some are simple while others bifurcate or appear capitate. Processes basal attachment to the vesical is curved. Processes communicate directly with the vesicle interior. Both vesicle and processes are psilate to shagrinate. Excystment is through a split in the side of the vesicle between the processes, rarely seen in compressional view.

**REMARKS**

This species is differentiated from *M. martae* and *M. irregulare* by having fewer processes whose furcated tips are rounded. It is differentiated from species A by having fewer and much thicker processes.

**DIMENSIONS**

Vd: 8-20 $\mu\text{m}$	Pl: 5-10 $\mu\text{m}$	Pw: 1.5-4 $\mu\text{m}$	Pn: 4-8	Sm: 6
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**GENUS *Navifusa* (Combaz et al. 1967) ex Eisenack et al. 1976**

TYPE SPECIES: *Navifusa navis* (Eisenack 1938a) Eisenack 1976

***Navifusa similis* (Eisenack) emend. Turner 1984**

Plate 9, fig. 6, 7

*Leiovalia similis* Eisenack, 1965a, p. 139, pl. 12, fig. 5-6; Uutella and Tynni, 1991, p. 76, pl. XVII, fig. 162.

*Navifusa similis* \*Turner 1984, p. 122, pl. 10, fig. 5.

*Navifusa teretis* Loeblich, 1970a, p. 731, figs. 24 C.

**DESCRIPTION**

Elongate, naviform vesicle with straight parallel sides and broadly rounded extremities. No processes or ornament. Vesicle wall is psilate, relatively thin and transparent, and about 0.5  $\mu\text{m}$  in thickness. Slight longitudinal folds and wrinkles are present. No excystment mechanism is observed.

**REMARKS**

This specimen is somewhat smaller and thinner than the original description, but all other morphological attributes are consistent with the type specimen. The Winterhouse material is typically infilled with pyrite giving the illustration in Plate 9, fig. 7 a verrucate texture appearance. Size variation suggest there may be more than one taxon here; the ratio of vesicle width versus vesicle length varies from  $\frac{1}{4}$  to  $\frac{1}{3}$ .

**DIMENSIONS**

VI: 55-134 $\mu\text{m}$	Vw: 20-50 $\mu\text{m}$	Sm: 13
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**PREVIOUS OCCURRENCES**

Lower Ordovician to Lower Silurian, Rapla Borehole, Estonia (Uutela and Tynni, 1991); Caradoc, Caradoc type sect., Britain (Turner, 1984); Middle Ordovician, Bromide Fm., U.S.A. (Loeblich, 1970a).

**GENUS *Ordoviciidium* Tappan and Loeblich 1971**

TYPE SPECIES: *Ordoviciidium elegantulum* Tappan and Loeblich 1971

***Ordoviciidium groetlingboenis* (Kjellström) Loeblich and Tappan 1978**

Plate 10, fig. 1

*Peteinosphaeridium groetlingboenis* Kjellström, 1971a, p. 52-53, pl. 4, fig. 1.

*Ordoviciidium elegantulum* Tappan and Loeblich, 1971, p. 389, pl. 7, figs. 1-7; Martin, 1980, p. 114, pl. 4, fig. 9; Turner, 1984, p. 124, pl. 2, fig. 4-6, pl. 8, fig. 1, 2, 4; Martin, 1983, p. 24, pl. 8, figs. 8-10, pl. 11, fig. 1, pl. 12, fig. 3.

*Ordoviciidium groetlingboenis* (Kjellström) Loeblich and Tappan, 1978, p. 1281; Jacobson, 1978b, p. 189, pl. V, fig. 15, pl. VI, fig. 1-3, 5, 6, 9, 11; Martin, 1983, p. 26, pl. 7, figs. 1, 4-5, pl. 8, figs. 1, 4, 7, 11, pl. 12, fig. 2; Uutela and Tynni, 1991, p. 100, pl. XXII, fig. 230. Jacobson, 1985, p. 188, pl. 7, fig. 1-3.

**DESCRIPTION**

Thick (1µm), spherical vesicle with well-spaced, cylindrical, broad stem, homomorphic furcated (first and second order) hollow processes. Processes arise from the outer wall layer of the vesicle and do not communicate with the vesicle interior. Processes have an angular basal contact with the vesicle and terminate with simple furcated tips. Processes are about 25 in number and in length about ½ of vesicle diameter. Vesicle wall is psilate while the processes are microgranular. No excystment mechanism observed.



**REMARKS**

*Ordoviciidium* is differentiated from *Peteinosphaeridium* in lacking the peteinos or laminae on its processes; it differs from *Multiplicisphaeridium* in that it does not communicate with the vesicle interior; it differs from *Baltisphaeridium* in not having the common plugs in the proximal portion of the process, instead its processes are separated from the vesicle interior by a simple wall layer.

**DIMENSIONS**

Vd: 33-59 $\mu\text{m}$	Pl: 7-17 $\mu\text{m}$	Pw: 2.5-5 $\mu\text{m}$	Pn: 14-36	Sm: 20
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**PREVIOUS OCCURRENCES**

Middle Ordovician, Rapla Borehole, Estonia (Uutela and Tynni, 1991); Caradoc, Caradoc type sect., England (Turner, 1984); Llanvirn-Caradoc, Bromide Fm., U.S.A. (Loeblich, 1971); Upper Ordovician, Kope and Fairview Fms., U.S.A. (Jacobson, 1978b); Caradoc, Sherman Fall Fm. and Lotbinière Fm., Canada (Martin, 1983); Ashgill, Vaureal Fm., Canada (Jacobson, 1985).

***Ordoviciidium heteromorphicum* (Kjellström) Loeblich and Tappan 1978**

Plate 10, fig. 2, 3

*Peteinosphaeridium heteromorphicum* Kjellström, 1971a, p. 53, pl. 4, fig. 2.

*Ordoviciidium heteromorphicum* (Kjellström) Loeblich and Tappan, 1978, p. 1281;  
Turner, 1984, p. 124; pl. 8, fig. 6; Uutela and Tynni, 1991, p. 101, pl. XXII, fig. 231.

**DESCRIPTION**

Spherical to sub-spherical vesicle. Processes are evenly-spaced on the surface of the vesicle. Processes arise from the outer wall layer and do not communicate with the vesicle interior. Processes are conical, heteromorphic with mainly simple and bifurcate tips. Processes have an angular attachment to vesicle. Processes, about 20 in number, are  $\frac{1}{3}$  of vesicle diameter in length. Vesicle is psilate; processes are microgranular. Excystment by partial rupture of vesicle wall.

**DIMENSIONS**

Vd: 42-55 $\mu\text{m}$	Pl: 12-17 $\mu\text{m}$	Pw: 2-4 $\mu\text{m}$	Pn: 18-28	Sm: 4
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**PREVIOUS OCCURRENCES**

Viruan (Llandeilo), Borehole No. 1, Baltic (Kjellström, 1971a); Caradoc, Caradoc type sect., England (Turner, 1984); Middle-Late Ordovician, Rapla Borehole, Estonia (Uutela and Tynni, 1991); Ordovician, Baltic erratics, Finland (Uutela, 1989).

***Ordovicidium* sp.**

Plate 10, fig. 4

**DESCRIPTION**

Spherical vesicle having numerous (ca. 80) heteromorphic conical processes with simple and bifurcated tips. Distal tips of pinnae are acuminate; pinnae curve back toward the vesicle and are  $\frac{1}{4}$  of the processes in length. Processes have a slightly curved proximal contact with the vesicle. Whether the processes communicate with the vesicle is uncertain. Both vesicle and processes are psilate. No excystment mechanism is observed.

**REMARKS**

This species is distinguished from *Excultibrachium concinnum* Loeblich and Tappan 1978 by having shorter pinnulae tips that do not drape back onto the vesicle wall.

This species has been differentiated from *O. heteromorphicum* by its shorter, thinner and more numerous processes.

**DIMENSIONS**

Vd: 51 $\mu$ m 33 $\mu$ m	Pl: 8 $\mu$ m 4 $\mu$ m	Pw: 3 $\mu$ m 1.5 $\mu$ m	Pn: ~ 80	Sm: 2
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**GENUS *Petaloferidium* Jacobson 1978a**

TYPE SPECIES: *Petaloferidium stigii* Jacobson 1978a

***Petaloferidium stigii* Jacobson 1978a**

Plate 11, fig. 1-3

*Petaloferidium stigii* Jacobson, 1978a, p. 296, pl. 1, figs. 5-6; Jacobson and Achab, 1985, p. 190, pl. 7, fig. 7.

**DESCRIPTION**

Subspherical to polygonal vesicle having conical, heteromorphic processes. Processes are in direct communication with the vesicle; basal contact with the vesicle is expanded and tips have both bulbous and other petaloid terminations. Some tips appear truncated and may be broken off. The process tips are typically darker in colour (perhaps thicker or solid) than the rest of the vesicle. Vesicle and process surfaces are scabrate-granulate, thin and always wrinkled, folded or torn. Processes are  $\frac{1}{3}$  the vesicle diameter in length. No excystment mechanism is observed.

**DIMENSIONS**

Vd: 49-77 $\mu\text{m}$	Pl: 19-33 $\mu\text{m}$	Pw: 3.5-5 $\mu\text{m}$	Pn: 11-20	Sm: 10
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**PREVIOUS OCCURRENCES**

Caradoc-Ashgill, Clays Ferry Fm., U.S.A. (Jacobson, 1978a); Ashgill, Vaureal Fm., Canada (Jacobson and Achab, 1985).

***Petaloferidium* sp.**

Plate 12, fig. 1-3

**DESCRIPTION**

Very thin ( $<0.5\ \mu\text{m}$ ), slightly corroded, sub-spherical vesicle with two robust, hollow, conical, heteromorphic processes. The processes are distributed randomly. Basal contact of the processes with the vesicle is expanded; processes are in direct communication with the vesicle; their heteromorphic tips having both bulbous, capitate and/or other petaloid terminations. The process tips are typically darker in colour (perhaps thicker) than the rest of the vesicle. The surface of vesicle and processes is scabrate-granulate, and highly corroded. Processes are  $\frac{1}{2}$  to  $\frac{1}{3}$  of the vesicle diameter in length. No excystment mechanism is observed.

**REMARKS**

This species is differentiated from *Petaloferidium stigii* by its spherical vesicle and two heteromorphic petaloid processes.

**DIMENSIONS**

Vd: 41-63 $\mu\text{m}$	Pl: 15-33 $\mu\text{m}$	Pw: 4-17 $\mu\text{m}$	Pn: 2	Sm: 10
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**GENUS *Poikilofusa* Staplin et al. 1965**

TYPE SPECIES: *Poikilofusa spinata* Staplin et al. 1965

***Poikilofusa* sp. cf. *P. spinata* (Staplin et al.) emend. Loeblich and Tappan 1978**

Plate 12, fig. 4

*Poikilofusa spinata* Staplin et al., 1965, p. 186, pl. 18, fig. 25-26; (Staplin et al.) emend. Loeblich and Tappan, 1978, p. 1282, pl. 12, fig. 8-9; Martin, 1980, p. 114, pl. 4, fig. 8; Jacobson and Achab, 1985, p. 189, pl. 8, fig. 2; Jacobson, 1978a, p. 92, fig. 1b.

**DESCRIPTION**

Vesicle is fusiform with two processes drawn out at opposite poles. Vesicle is well developed, inflated, symmetrical, and ornamented with numerous small spines that decrease in size towards the base of the processes. The processes are psilate, conical in shape with acuminate distal terminations. Processes are  $\frac{1}{2}$  of the vesicle width (Vw) in length. No excystment mechanism is observed.

**REMARKS**

Winterhouse species differs from the original description of Staplin et al. (1965) in that it does not have the longitudinal striations or spines that occur in longitudinal rows.

**DIMENSIONS**

V. (61x25) $\mu$ m (25x15) $\mu$ m	Pl: 15 $\mu$ m	Pw: 2 $\mu$ m	Pn: 2	Sm: 2
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**PREVIOUS RECORDS**

Late Ordovician, Trenton Fm., Canada (Staplin et al., 1965); Ashgill, Vaureal Fm., Canada (Jacobson and Achab, 1985); Late Ordovician, Whitehead Fm., Canada (Martin, 1980); Late Ordovician, Clay Ferry Fm., U.S.A (Jacobson, 1978a).

**GENUS *Polyancistrodorus* Loeblich and Tappan 1969**

TYPE SPECIES: *Polyancistrodorus columbariferus* Loeblich and Tappan 1969

***Polyancistrodorus* sp. cf. *P. columbariferus* Loeblich and Tappan 1969**

Plate 10, fig. 5-9

*Polyancistrodorus columbariferus* Loeblich and Tappan, 1969, p. 52, pl. 2, fig. 1-5; Uutela and Tynni, 1991, p. 107, pl. XXIVV, fig. 256.

**DESCRIPTION**

A thick-walled (1 $\mu$ m) spherical vesicle having numerous (ca. 40) homomorphic and either trifurcated or quadrifurcated pyramid shaped processes. Processes may have three or four lamina faces that join the vesicle with an angular contact. Processes are extremely thin (<0.25  $\mu$ m) and serrated in appearance along the lamina edge (where two sides of the process trunk

join). This serrated margin does not extend all the way to the process base but stops  $\frac{1}{2}$  to  $\frac{3}{4}$  of the way down. Processes are not in communication with the vesicle interior, they appear to be a solid extension of the outer surface layer. Both pylome diameter and process lengths are  $\frac{1}{4}$  that of the vesicle's diameter. The vesicle surface appears scabrate in transmitted light but is definitely microfoveolate when seen in SEM; the processes are psilate. Excystment is through a rimmed pylome which may have a psilate operculum attached. No pseudopylome is observed.

#### REMARKS

*Polyancistrodorus* is differentiated from *Peteinosphaeridium* in having a thickened pseudopylome similar to *Axisphaeridium*. It differs from the latter in the complexity of its processes.

This author could not clearly identify the pseudopylome described by Loeblich and Tappan (1969) and is therefore designated cf., but its morphology is more akin to *Polyancistrodorus* than *Peteinosphaeridium*. An operculum measured 12.5  $\mu\text{m}$  in diameter on one specimen.

#### DIMENSIONS

Vd: 41-65 $\mu\text{m}$	Pl: 7-10 $\mu\text{m}$	Pw: 2-5 $\mu\text{m}$	Pn: 38-50	Sm: 6
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**PREVIOUS OCCURRENCES**

Middle Ordovician, Bromide Fm., U.S.A. (Loeblich and Tappan, 1969); Middle to Late Ordovician, Rapla Borehole, Estonia (Uutela and Tynni, 1991).

**GENUS *Polygonium* Vavrdová 1966**

TYPE SPECIES: *Polygonium gracile* Vavrdová 1966

***Polygonium connectum* (Kjellström) emend. Sargent and Stancliffe 1994**

Plate 13, fig. 1, 2

*Goniosphaeridium connectum* Kjellström, 1971a, p. 44, pl. 3, fig. 5; Kjellström, 1976, p. 30, fig. 23.

*Polygonium connectum* (Kjellström) Sargent and Stancliffe, 1994, p. 68.

**DESCRIPTION**

A subspherical to polygonal vesicle having wide (up to 10 µm), simple, homomorphic, conical processes that taper gently and terminate with rounded to acuminate distal tips. Process lengths less than vesicle diameter. The distal portion of some processes exhibit secondary infill or thickening which is usually darker in appearance than the unfilled portion. Processes are in direct communication with the vesicle. Vesicle and process surfaces are psilate to shagrinate and wrinkled. No excystment mechanism observed.

**DIMENSIONS**

Vd: 33-63 $\mu\text{m}$	Pl: 16-53 $\mu\text{m}$	Pw: 5-12 $\mu\text{m}$	Pn: 14-26	Sm: 8
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**PREVIOUS OCCURANCES**

Middle Ordovician, Borehole No. 1, Götland (Kjellström, 1971a; 1976).

***Polygonium gracile* Vardová 1966**

Plate 13, fig. 3,4

*Polygonium gracile* Vardová, 1966, p. 412-413, pl. 7, figs. 8-9; Jacobson and Achab, 1985, p. 192-193, pl. 7, figs. 8-9.

*Goniosphaeridium splendens* \*Turner, 1984, p. 113-114, pl. 13. figs. 3-5; Uutela and Tynni, 1991, p. 67, pl. XII, fig. 126.

**DESCRIPTION**

A sub-polygonal to polygonal vesicle with simple homomorphic conical processes. Processes are in direct communication with the vesicle, with expanded bases and acuminate tips. Processes do not exceed the vesicle diameter in length. Both vesicle and process surfaces are psilate to shagrinate. No excystment mechanism is observed.

**DIMENSIONS**

Vd: 22-30 $\mu\text{m}$	Pl: 10-24 $\mu\text{m}$	Pw: 1.5-2 $\mu\text{m}$	Pn: 12-20 $\mu\text{m}$	Sm: 10
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**PREVIOUS OCCURRENCES**

Caradoc, Caradoc type sect., Britain (Turner, 1984); Early Ordovician-Early Silurian, Rapla Borehole, Estonia (Uutela and Tynni, 1991); Ashgill, Vaureal Fm., Canada (Jacobson and Achab, 1985).

***Polygonium tenuispinosum* Uutela and Tynni 1991**

Plate 13, fig. 5, 6

*Goniosphaeridium tenuispinosum* Uutela and Tynni, 1991, p. 67, pl. X111, fig. 132.

**DESCRIPTION**

A thin polygonal to sub-rounded vesicle with simple, homomorphic, flagelliform processes. These processes communicate freely with the vesicle and join by a curved proximal contact. Tips are acuminate. Processes are  $\frac{1}{2}$  to  $\frac{3}{4}$  of the vesicle diameter in length. Processes have a microgranulate ornament which may extend on to the vesicle. Excystment through a marginal split.

**REMARKS**

This species is distinguished from *P. gracilis* Vardová 1966 in having processes that show a microgranular ornament.

**DIMENSIONS**

Vd: 16-30 $\mu\text{m}$	Pl: 12-15 $\mu\text{m}$	Pw: 2-4 $\mu\text{m}$	Pn: 10-20	Sm: 5
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**PREVIOUS OCCURRENCES**

Early to Middle Ordovician, Rapla Borehole, Estonia (Uutela and Tynni, 1991).

***Polygonium* sp. A**

Plate 13, fig. 7, 8

*Polygonium* sp. A Wright and Meyers, 1981, p. 28, pl. 7, fig. G.

**DESCRIPTION**

A polygonal vesicle having straight to slightly inflated sides of various lengths. All processes are conical with expanded bases; distal tips are acuminate. Processes vary in size, communicate freely with the vesicle interior and appear in more than one plane. All processes are similar to or shorter than the vesicle diameter in length. There appears to be one dominant process which stands out quite distinctly from the other processes and gives the vesicle a triangular appearance. Vesicle and processes are psilate to slightly granulate. No excystment mechanism is observed although the vesicle is often split.

**DIMENSIONS**

Vd: 20-33 $\mu$ m	Pl: 12-16	Pw: 3-5	Pn: 11-14	Sm: 3
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**PREVIOUS OCCURRENCES**

Caradoc-Ashgill, Maquoketa Sh., U.S.A. (Wright and Meyers, 1981).

***Polygonium* sp. B**

Plate 13, fig. 9

**DESCRIPTION**

Large polygonal vesicle having numerous, broad base (bell to triangular shape), conical homomorphic processes of different lengths from  $\frac{1}{3}$  to  $\frac{1}{2}$  of the vesicle diameter. Length of the processes decrease in size from the outer margin of the vesicle towards its centre. Processes communicate with the vesicle interior and terminate with acuminate tips. Vesicle and processes are shagrinated. No excystment mechanism is observed.

**REMARKS**

This species has been separated from similar species because of its unique appearance in that its processes have very broad, bell like to triangular shaped bases which are unlike the conical well-tapered bases of other *Polygonium* species described above.

**DIMENSIONS**

Vd: 41 $\mu$ m	Pl: 19 $\mu$ m	Pw: 12 $\mu$ m	Pn: 23	Sm: 1
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***Polygonium* sp. C**

Plate 13, fig. 10, 11

**DESCRIPTION**

A slightly elongated, polygonal vesicle having numerous (ca. 50) simple, homomorphic processes which communicate freely with the vesicle interior. Processes join the vesicle with a curved proximal contact and terminate with acuminate tips. Processes are  $\frac{1}{3}$  of the vesicle diameter in length. Both vesicle and processes are psilate. No excystment mechanism is observed.

**REMARKS**

This species is differentiated from other *Polygonium* species because of its numerous (ca. 50) shorter, non-ornamented processes.

**DIMENSIONS**

Vd: 25-46 $\mu\text{m}$	Pl: 10-22 $\mu\text{m}$	Pw: 1.5-4 $\mu\text{m}$	Pn: 30-60	Sm: 7
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**GENUS *Pterospermella* Eisenack 1972**

TYPE SPECIES *Pterospermella aureolata* (Cookson and Eisenack 1958) Eisenack 1972

***Pterospermella* sp.**

Plate 14, fig. 1, 2

**DESCRIPTION**

Spherical central body surrounded by an equatorial flange; central vesicle wall is 1  $\mu\text{m}$  thick and appears scabrate or microfoveolate. The surrounding flange is relatively thin and flimsy with some folding; it has no identifiable veins or supporting rods; its surface is scabrate to granulate; and its perimeter is circular but not well defined, possibly thinning towards the edges. The flange is  $\frac{1}{2}$  of the vesicle diameter in width. No obvious excystment mechanism.

**DIMENSIONS**

Vd: 24 $\mu\text{m}$ 35 $\mu\text{m}$	Flange width: 10 $\mu\text{m}$ 20 $\mu\text{m}$	Sm: 2
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**GENUS *Rhachosoarium* Tappan and Loeblich 1971**

TYPE SPECIES: *Rhachosoarium lappaceum* Tappan and Loeblich 1971

***Rhachosoarium lappaceum* Tappan and Loeblich 1971**

Plate 14, fig. 3, 4

*Rhachosoarium lappaceum* Tappan and Loeblich, 1971, p. 404, pl. 6, figs. 6-7.

**DESCRIPTION**

Vesicle elongated with broadly rounded poles. Homomorphic processes are simple with expanded proximal bases and acuminate distal tips. Processes are somewhat flexible and communicate freely with the vesicle interior. They are well spaced and evenly distributed on the vesicle. Processes are  $\frac{1}{4}$  the vesicle maximum diameter in length. Both vesicle and processes are psilate. Excystment is by simple rupture of the vesicle wall.

**REMARKS**

This species is differentiated from *Polygonium* by its elongate naviform appearance. It is differentiated from *Navifusa* by having processes.

**DIMENSIONS**

V: (38x66) $\mu\text{m}$ (25x48) $\mu\text{m}$	Pl: 7 $\mu\text{m}$ 10 $\mu\text{m}$	Pw: 2 $\mu\text{m}$	Pn: ~50	Sm: 2
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**PREVIOUS OCCURRENCES**

Caradoc- Ashgill, Eden Fm., U.S.A. (Tappan and Loeblich, 1971).

**GENUS *Uranidium* Jacobson and Achab 1985**

TYPE SPECIES: *Uranidium semicalvum* Jacobson and Achab 1985

***Uranidium semicalvum* Jacobson and Achab 1985**

Plate 15, fig. 1, 2

*Uranidium semicalvum* Jacobson and Achab, 1985, p. 193-194; pl. 5, figs. 1-5.

**DESCRIPTION**

Spherical to subspherical vesicle;  $\frac{3}{4}$  of the vesicle has solid hair-like ornament while the other  $\frac{1}{4}$  of the vesicle is psilate. The well-spaced ornament (1.5-2  $\mu\text{m}$  high and less than 1  $\mu\text{m}$  wide with pointed to rounded extremities) is concentrated at one pole and becomes less dense and shorter in length towards the other pole where it disappears altogether. Excystment is by means of a marginal split.

**REMARKS**

This species is similar to *Dasydorus cirritus* Playford and Martin 1984 but does not have that species distinct tapered, egg shaped apex.

**DIMENSIONS**

Vd: 22-33 $\mu\text{m}$	Sm: 10
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**PREVIOUS OCCURRENCES**

Ashgill, Vaureal Fm., Canada (Jacobson and Achab, 1985).

**GENUS *Veryhachium* (Deunff 1954) emend. (Downie and Sarjeant 1963)**

**emend. Turner 1984**

TYPE SPECIES: *Veryhachium trisulcum* (Deunff 1951) ex. Deunff 1959

***Veryhachium downiei* Stockmans and Willière 1962**

Plate 15, fig. 3, 4

*Veryhachium downiei* Stockmans and Willière, 1962, p. 451-452, pl. 1, fig. 9.

**DESCRIPTION**

Triangular vesicle, sides straight to slightly inflated, rarely concave. Three simple, flagelliforme homomorphic processes arise from the corners and are in direct communication with the vesicle. Process tips are acuminate; basal contact with the vesicle is curved. Processes are flexible and easily distinguished from the vesicle; their lengths are greater than that of the vesicle diameter. Both vesicle and processes are psilate. Excystment is by an epityche.

**DIMENSIONS**

Vd : 16-20 $\mu\text{m}$	Pl: 28-38 $\mu\text{m}$	Pw: 2.8-5.5 $\mu\text{m}$	Sm: 5
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**PREVIOUS OCCURRENCES**

Tramadoc to Frasnian deposits (Eisenack et al., 1979b).

***Veryhachium oklahomense* Loeblich 1970a**

Plate 15, fig. 1

*Veryhachium oklahomense* Loeblich, 1970a: p. 742, fig. 36 f, g; Molyneux and Paris, 1985, p. 11, pl. 4, fig. 4-7, pl. 4, fig. 10-11; Molyneux, 1988 p. 51, pl. 11, fig. 12; Uutela and Tynni, 1991 p.121, pl. XXX, fig. 314.

**DESCRIPTION**

A small rectangular to square vesicle, sides always straight to concave, never convex. There are four homomorphic flagelliform processes at each corner in the plane of the central body. Processes communicate freely with the vesicle interior, have acuminate distal tips, and curved proximal contacts. Processes are up to 2x the vesicle diameter in length. Both vesicle and processes are psilate. No excystment mechanism is observed.

**DIMENSIONS**

Vd: 8-15 $\mu\text{m}$	Pl: 11-20 $\mu\text{m}$	Pw: 1-4 $\mu\text{m}$	Sm: 13
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**PREVIOUS OCCURRENCES**

Ashgill, Sylvan Sh., U.S.A. (Loeblich, 1970a); Caradoc-Ashgill, Maquoketa Sh., U.S.A. (Wright and Meyers, 1981); Caradoc, Caradoc type sect., England (Turner, 1984). Late Ordovician: Libya (Molyneux and Paris, 1985; Molyneux, 1988); Early-Late Ordovician, Rapla Borehole, Finland (Uutela and Tynni, 1991).

***Veryhachium rhomboidium* (Downie) emend. Turner 1984**

Plate 15, fig. 6

*Veryhachium rhomboidium* Downie, 1959, p. 62-63, pl. 12, fig. 10; \*Turner, 1984 p. 145, pl. 11, fig. 6, 9; Uutela and Tynni, 1991, p. 122, pl. XXX, fig. 317.

**DESCRIPTION**

Rhomboid vesicle. Processes are simple, conical, homomorphic with acuminate distal tips and curved proximal bases. Four processes arise from the corners of the vesicle and communicate freely with its interior; other processes (1-3) lie perpendicular to those in the plane of the central body and also communicate directly with the vesicle interior. The surfaces of the vesicle and processes are psilate. Length of processes rarely exceeds the maximum length of the vesicle. Excystment mechanism by an epityche.

**DIMENSIONS**

Vd: 7.5-24 $\mu\text{m}$	Pl: 5-20 $\mu\text{m}$	Pw: 1-4 $\mu\text{m}$	Pn: 5-7 $\mu\text{m}$	Sm: 32
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**PREVIOUS OCCURRENCES**

Caradoc, Caradoc type sect., Britain (Turner, 1984); Lower Silurian, Rapla Borehole, Estonia (Uutela and Tynni, 1991).

***Veryhachium trispinosum* (Eisenack) Stockmans and Willère 1962**

Plate 15, fig. 7

*Hystriosphæridium trispinosum* Eisenack, 1938a, p. 14, fig. 2, 3.

*Veryhachium trispinosum* (Eisenack) Stockmans and Willère, 1962, p. 46-47;

\*Turner, 1984, p.146, pl. 11, fig. 3; Molyneux and Paris, 1985, p. 11, pl. 3, fig. 1; Uutela and Tynni, 1991, p. 123, Pl. XXX, fig. 319.

**DESCRIPTION**

Triangular shaped vesicle with sides equal in length. Sides are straight to concave, rarely convex. Three simple conical homomorphic processes arise from the corners. Processes communicate freely with the vesicle interior, have acuminate distal tips and curved proximal contacts. Process bases may not be easily distinguished from the vesicle, and their lengths are shorter than the vesicle diameter in length. Both vesicle and processes are psilate and typically wrinkled. No excystment mechanism is observed.

**REMARKS**

This species shows quite a variation in the size in Winterhouse Formation. It is differentiated from *V. reductum* Deunff 1959 by not having a granular ornament.

**DIMENSIONS**

Vd: 19-37 $\mu\text{m}$	Pl: 8-22 $\mu\text{m}$	Pw: 2.2-5.5 $\mu\text{m}$	Sm: 45
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**PREVIOUS OCCURRENCES**

Ordovician, Baltic (Eisenack, 1938a); Caradoc, Caradoc type sect., England (Turner, 1984); Late Ordovician, Libya (Molyneux and Paris, 1985); Middle Ordovician, Rapla Borehole, Estonia (Uutela and Tynni, 1991).

***Veryhachium valiente* Cramer 1964**

Plate 16, fig. 2

*Veryhachium valiente* Cramer, 1964, p. 311, pl. 12, fig. 3-4, 6; \*Loeblich, 1970a, fig. 36 C-E.

*Veryhachium lairdii* Molyneux and Paris, 1985, p. 11, pl. 4, fig. 10-11; Molyneux, 1988, p. 51, pl. 11, fig. 9; Uutela and Tynni, 1991, p. 121, pl. XXX, fig. 312.

**DESCRIPTION**

A rectangular vesicle with relatively straight sides. There are four homomorphic flagelliform processes at each corner in the plane of the central body. Processes are similar to, or slightly smaller than the longest side in length. Processes communicate freely with the vesicle interior, have acuminate distal tips and curved proximal contacts. Both vesicle and processes are psilate. Excystment by a split in the side wall located between two processes.

**DIMENSIONS**

VI: 6-33 $\mu\text{m}$	Vw: 10-25 $\mu\text{m}$	Pl: 3-24 $\mu\text{m}$	Pw: 1-5 $\mu\text{m}$	Sm: 50
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**PREVIOUS OCCURRENCES**

Middle Silurian, Maplewood Sh., U.S.A. (Loeblich, 1970a); Late Ordovician, Libya (Molyneux and Paris, 1985; Molyneux, 1988). Early-Late Ordovician, Rapla Borehole, Estonia (Uutela and Tynni, 1991).

**GENUS *Villosacapsula* Loeblich and Tappan 1976**

TYPE SPECIES: *Villosacapsula setosapellicula* Loeblich 1970a

***Villosacapsula entrichos* (Loeblich) Loeblich and Tappan 1976**

Plate 16, fig. 3, 4

*Veryhachium entrichos* Loeblich, 1970a, p. 740, fig. 34 F.

*Villosacapsula entricos* (Loeblich) Loeblich and Tappan, 1976, p. 307.

**DESCRIPTION**

Triangular vesicle; sides inflated giving the vesicle a rounded appearance. Three simple conical homomorphic processes arise from the corners and are in direct communication with the vesicle. Process tips are acuminate; basal contact with the vesicle is curved. Processes are stiff, not flexible, and are easily distinguished from the vesicle; their length is less than  $\frac{1}{4}$  of the vesicle diameter. Both vesicle and processes have hairlike ornament which is more

noticeable in SEM than transmitted light. Excystment mechanism is an epityche.

#### REMARKS

This species differs from *V. setosapellicula* Loeblich 1970a in having shorter processes and a finer ornament that is barely noticeable in transmitted light.

#### DIMENSIONS

Vd: 19-32 $\mu\text{m}$	Pl: 5-8 $\mu\text{m}$	Pw: 2 $\mu\text{m}$	Sm: 8
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#### PREVIOUS OCCURRENCES

Caradoc, Bromide Fm., U.S.A. (Loeblich, 1970a).

#### *Villosacapsula irroratum* (Loeblich and Tappan) Fensome et al. 1990

Plate 15, fig. 5

*Veryhachium irroratum* Loeblich and Tappan, 1969, p. 56, pl. 3, fig. 1-9, pl. 4, fig. 1-4; Legault, 1982, p. 1855, pl. 2, fig. 1; Martin, 1983, p. 29, pl. 6, fig. 7, pl. 8, fig. 12, pl. 11, fig. 24.

*Villosacapsula irroratum* (Loeblich and Tappan) Fensome et al., 1990, p. 529.

#### DESCRIPTION

Triangular vesicle; sides inflated giving the vesicle a rounded appearance. Three simple conical homomorphic processes arise from the corners and are in direct communication with



the vesicle. A fourth process extends from the face of the vesicle. Process tips are acuminate; basal contact with the vesicle is curved. Processes are stiff, not flexible, and easily distinguished from the vesicle; their lengths are equal to the vesicle diameter. Both vesicle and processes are shagrinose to granulate. No excystment mechanism is observed.

#### **DIMENSIONS**

Vd: 25 $\mu\text{m}$	Pl: 30 $\mu\text{m}$	Pw: 5 $\mu\text{m}$	Pn: 4 $\mu\text{m}$	Sm: 1 $\mu\text{m}$
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#### **PREVIOUS OCCURRENCES**

Middle Ordovician, Bromide Fm., U.S.A. (Loeblich and Tappan, 1969); Caradoc-Ashgill, Orphan Knoll, Canada (Legault, 1982); Early Ordovician, Laval Fm., Canada (Martin, 1983).

#### ***Villosacapsula setosapellicula* (Loeblich) Loeblich and Tappan 1976**

Plate 16, fig. 5-8

*Villosacapsula setosapellicula* Loeblich, 1970a, p. 743, figs. 36A, B, 37A, B; Colbath, 1979, p. 29, pl. 14, fig. 7; Loeblich and Tappan, 1976, p. 307; Wright and Meyers, 1981, p. 37, pl. 3, fig. 1; Martin, 1983, p. 59, pl. 12, fig. 17; Turner, 1984, p. 158, pl. 12, figs. 5, 7; Molyneux and Paris, 1985, p. 16, pl. 3, fig. 3; Elouad-Debbaj, 1988, p. 240, pl. 2, fig. 13-15, 18.

#### **DESCRIPTION**

Sub-spherical to triangular-shaped vesicle; hollow, inflated giving the sides a definite convex

outward appearance. Two to four (typically three) conical processes with acuminate tips lie within the compressional view of the central body; these arise from, and communicate freely with the vesicle interior. The process have a curved contact with the vesicle; their lengths are approximately  $\frac{1}{2}$  of the vesicle diameter. The vesicle and process wall is 0.5-1  $\mu\text{m}$  thick and is ornamented with hairlike, flexible solid micro-spines, 1- 2  $\mu\text{m}$  long and evenly distributed. Depending on the viewing orientation, the ornament may look granular. No excystment mechanism is observed.

#### **DIMENSIONS**

Vd: 15-32 $\mu\text{m}$	Pl: 7-21 $\mu\text{m}$	Pw: 2-7 $\mu\text{m}$	Sm: 39
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#### **PREVIOUS OCCURRENCES**

Ashgill, Sylvan Sh., U.S.A. (Loeblich, 1970a); Late Ordovician, Eden Sh., U.S.A. (Colbath, 1979). Caradoc-Ashgill, Maquoketa Sh., U.S.A. (Wright and Meyers, 1981); Middle Ordovician, Trenton Fm., Canada (Martin, 1983); Caradoc, Caradoc type sect., England (Turner, 1984); Late Ordovician, Libya (Molyneux and Paris, 1985); Ashgill, Morocco (Elouad-Debbaj, 1988); Ashgill, Jordan (Keegan et al., 1990).

**Division Chlorophycophyta**

**Class Prasinophyceae**

**GENUS *Cymatiosphaera* (Wetzel 1933) emend. Deflandre 1954**

TYPE SPECIES: *Cymatiosphaera radiata* O. Wetzel 1933

***Cymatiosphaera* sp. A.**

Plate 17, fig. 1, 2

**DESCRIPTION**

Vesicle circular in outline; surface divided by (ca. 22) pentagonal lacunae attached to each other by their muri. Lacunae are shagrinate while the muri are psilate. There is a fine line which runs down the centre of each murus as seen in light microscope, it looks as if two muri are joined together. No excystment mechanism is observed.

**DIMENSIONS**

Vd: 40 $\mu$ m 57 $\mu$ m	Diameter of lacuna: 4, 6 $\mu$ m	Thickness of murus: 1.5, 2 $\mu$ m	Lacunae in optical section: 20-24	Sm: 2
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***Cymatiosphaera* sp. B**

Plate 17, fig. 3, 4

**DESCRIPTION**

Vesicle circular in outline, surface divided by (ca. 10) pentagonal lacunae attached to each other by their muri. There is a fine line which runs down the centre of each murus as seen in light microscope, it looks as if two muri are joined together. Lacunae are shagrinate while the muri are psilate. No excystment mechanism is observed.

**REMARKS**

This species is separated from species A by the fewer number of lacunae and smaller vesicle size.

**DIMENSIONS**

Vd: 33 $\mu$ m 38 $\mu$ m	Diameter of lacuna: 8, 10 $\mu$ m	Thickness of murus: 3 $\mu$ m	Lacunae in optical section: 10-12?	Sm: 2
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**GENUS *Leiosphaeridia* (Eisenack 1958a) emend. (Downie and Sargeant 1963)**

**emend. Turner 1984**

TYPE SPECIES: *Leiosphaeridia baltica* Eisenack 1958a

***Leiosphaeridia* ssp.**

Plate 17, fig. 5-7

**DESCRIPTION**

All spherical vesicles that are psilate, shagrinata or slightly granulate, with no observable excystment mechanism.

**REMARKS**

This genus is treated collectively without identification of individual species.

**ANTETURMA Cryptospore Richardson et al. 1984****Cryptospore sp. A**

Plate 18, fig. 1, 2

**DESCRIPTION**

Simple tetrad. Individual cells are up to 1.5  $\mu\text{m}$  thick, spherical and appear scabrate.

**REMARKS**

(Sm) refers whole tetrad not individual spore.

**DIMENSIONS**

Individual cells are 18-30 $\mu\text{m}$ each.	Sm: 8
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**Cryptospore sp. B**

Plate 18, fig. 3-6

**DESCRIPTION**

An oval shaped spore (?) having a central oval body. The central body has a rhomboidal H-shaped tetrad. The outer envelope that surrounds the central body may or may not be developed. On one side of the spore the envelope (when developed) appears to have a thickening which curves and extends diagonally across the longitudinal axis of the inner body, this feature may be a folding of the outer wall layer. Both the central body and the envelope is scabrate with a dense ornament of echinate spines. Spines on different specimens vary in size from 0.25-1  $\mu\text{m}$ .

**REMARKS**

It appears that this species shows a variety of forms which might reflect stages in development. Some specimens have a very coarse ornament of spines while on others the ornament is not so clearly defined. The size of the central body to the enclosing envelope is also quite variable. In some specimens the inner body is quite large with respect to the enclosing envelope (see Plate 18, fig. 6) while other specimens (see Plate 18, fig. 5) the inner body is relatively small with respect to the enclosing envelope.

**DIMENSIONS**

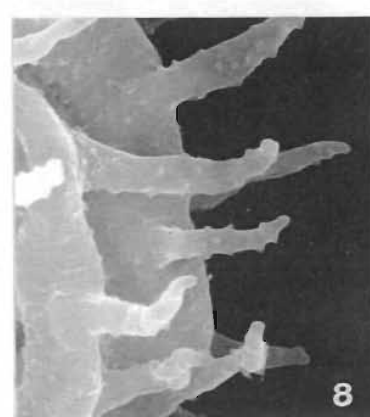
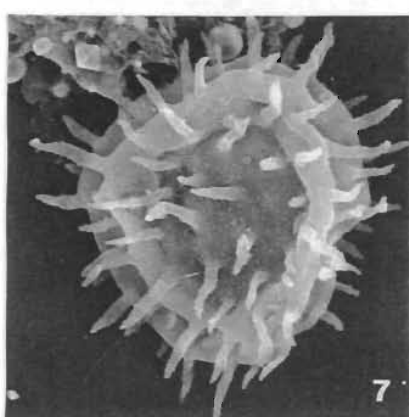
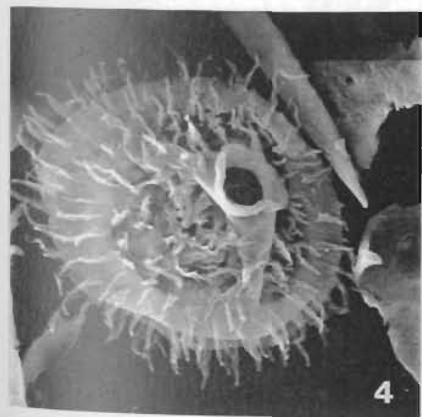
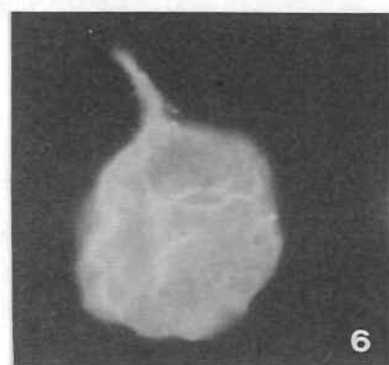
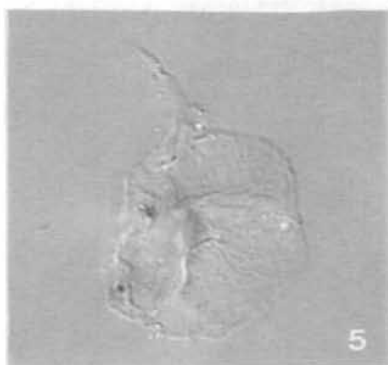
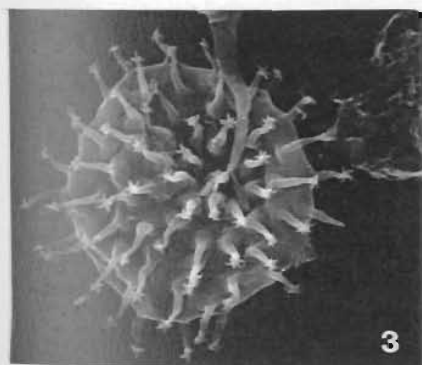
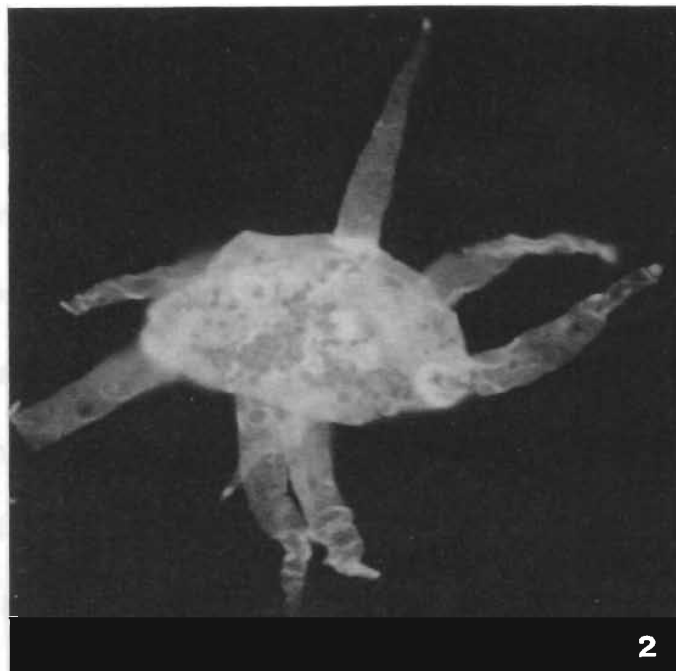
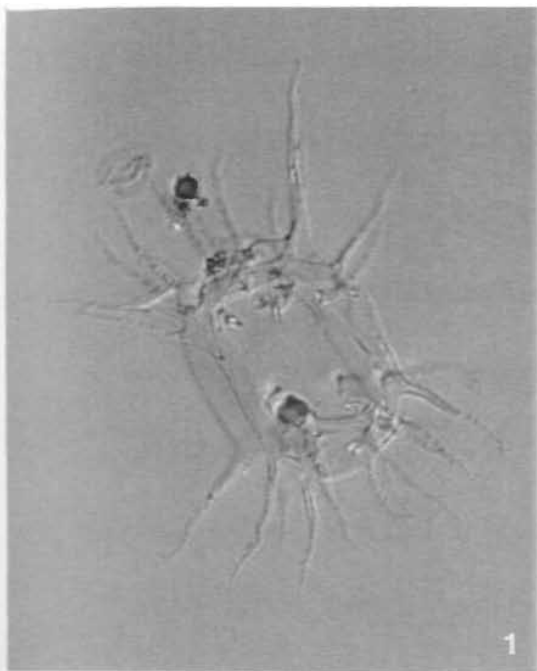
Inner cell body: (10-19)x (20-27) $\mu\text{m}$	Enclosing envelope: (20-35) x (30-55) $\mu\text{m}$	Sm: 13
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**PLATE 1**

- 1 *Actinotodissus crassus* Loeblich and Tappan 1978, P95287 3/3 unox, P61/3, x1135.
- 2 *Actipilion druggii* Loeblich 1970a, P95272 1 unox, J38/1, x720.
- 3 *Ammonidium parvipinnatum* Uutela and Tynni 1991, P97057 <33µm, L8, x1180.
- 4 *Axisphaeridium tricolumnelar* Uutela 1989, P97061 >33µm, M3, x540, showing pylome with raised collar.
- 5, 6 *Bacisphaeridium* sp., 5: P95424 1 unox, F48/2, x1135; 6: P95424 1 unox, F48/2 fluorescent light, x1135.
- 7, 8 *Baltisphaeridium accinctum* Loeblich and Tappan 1978. 7: P97061 >33µm, M3, x600; 8: P97061 >33µm, M3, x2700, higher magnification of fig. 7 showing detail surface ornament on vesicle and processes.

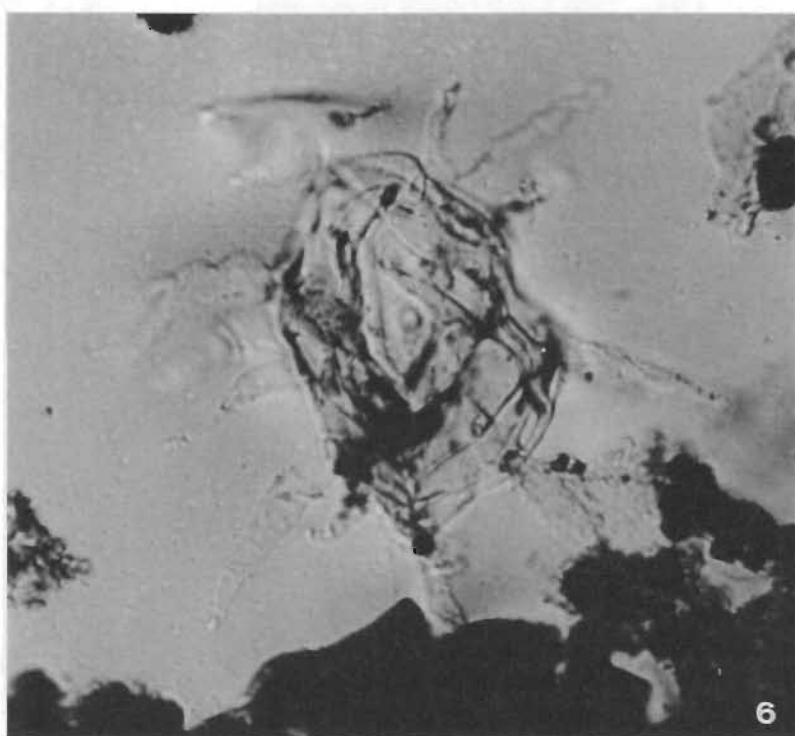
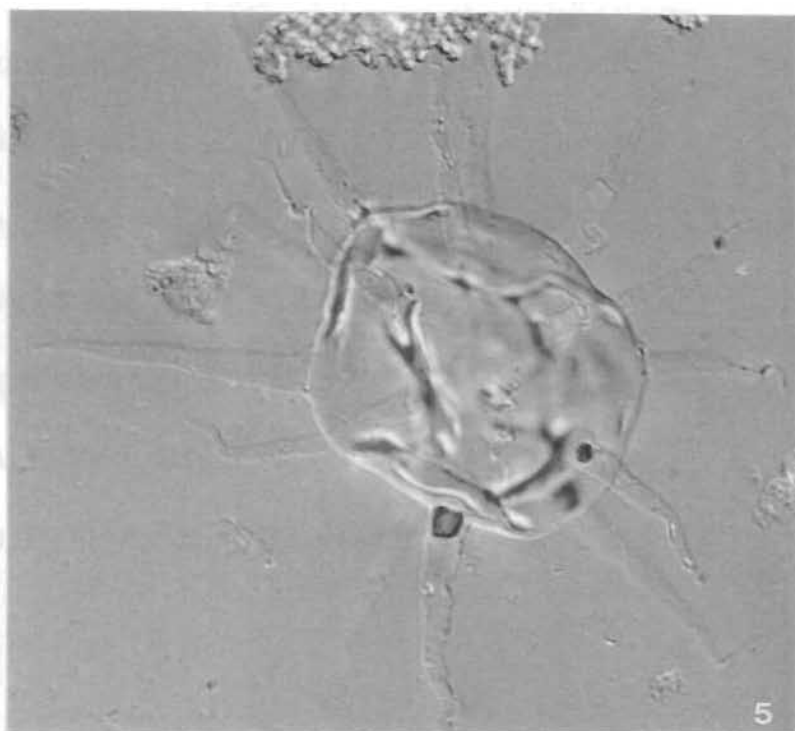
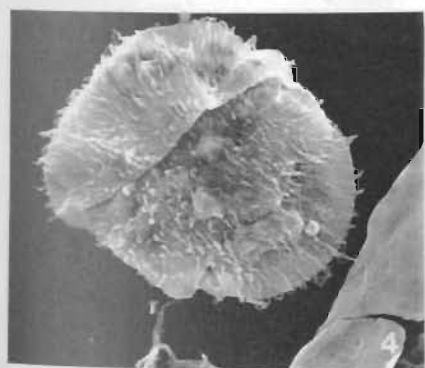
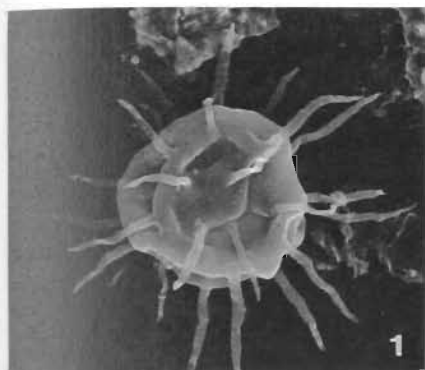
PLATE 1



**PLATE 2**

- 1     *Baltisphaeridium aspersihumiferum* Loeblich and Tappan 1978, P97059 >33µm, F5, x540, showing granules on processes.
- 2     *Baltisphaerium brevifilicum* Kjellström 1971a, P97059 >33µm, L3, x600.
- 3     *Baltisphaeridium filiosum* Kjellström 1971a, P97058 <33µm, K8, x1350.
- 4     *Baltisphaeridium nanninum* Eisenack 1965b, P97059 >33µm, S4, x540.
- 5     *Baltisphaeridium* sp., P95272 1 unox, K44/0, x1135.
- 6     *Baltisphaerosum dispar* Turner 1984, P97028 ½ unox, O46/0, x720, granular processes are showing constricted basal attachment to the vesicle.

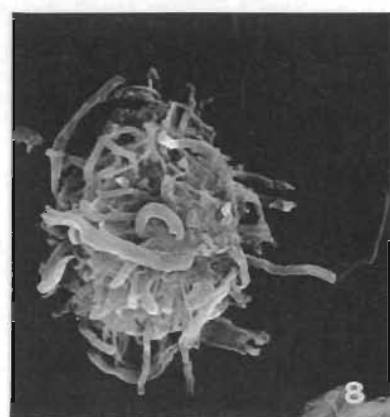
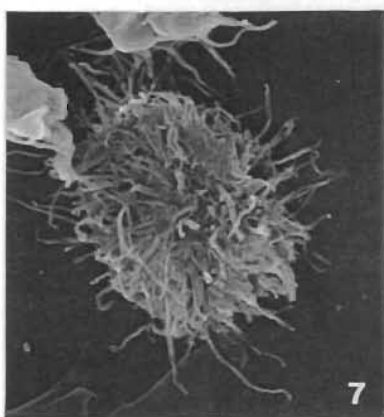
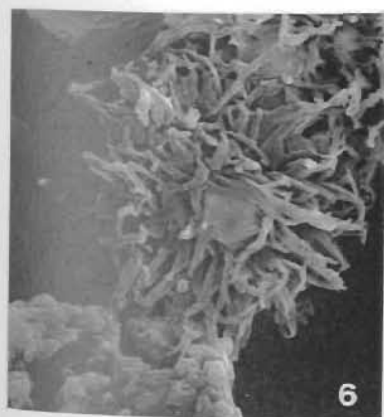
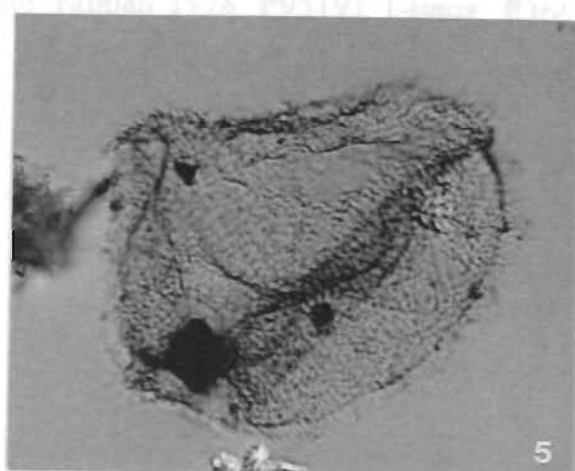
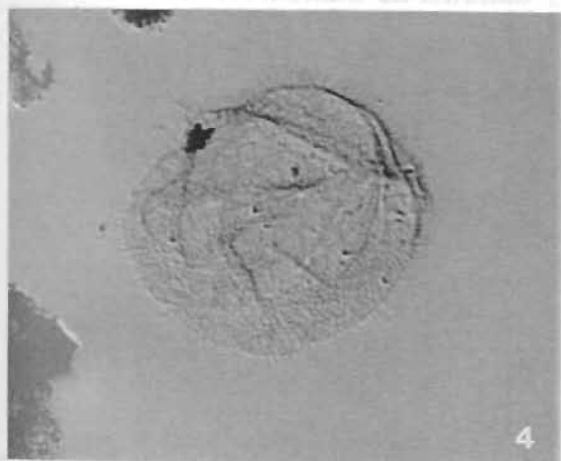
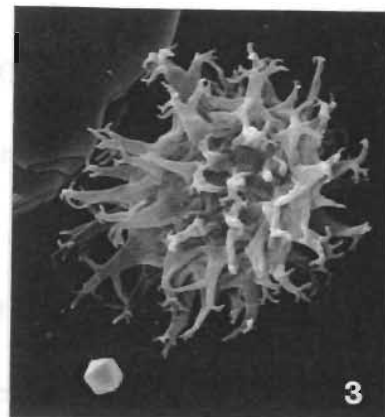
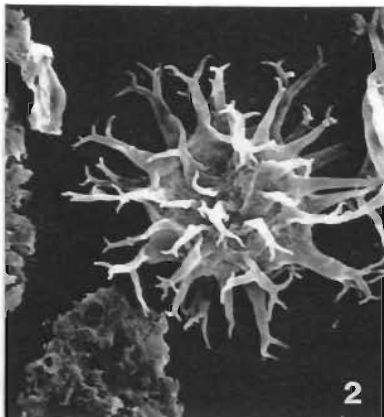
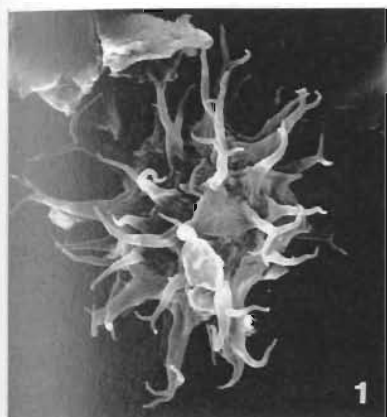
PLATE 2



**PLATE 3**

- 1     *Cheleutochroa diaphorosa* Turner 1984, P97059 <33µm, B2, x1190.
- 2, 3   *Cheleutochroa* sp. 2: P97058 <33µm, H3, x920; 3: P97057 <33µm, M5, x1350.
- 4, 5   *Comasphaeridium lanugiferum* Jacobson and Achab 1985; 4: P95434 1/2 unox, H28/2, x1135; 5: P95286 3/3 siev, S38/1, x1135.
- 6     *Comasphaeridium varispinosum* Uutela 1989, P97057 <33µm, I5, x1884.
- 7     *Comasphaeridium* sp. A, P97057 <33µm, N6, x1190.
- 8     *Comasphaeridium* sp. B, P97057 <33µm, B2, x1190.

PLATE 3

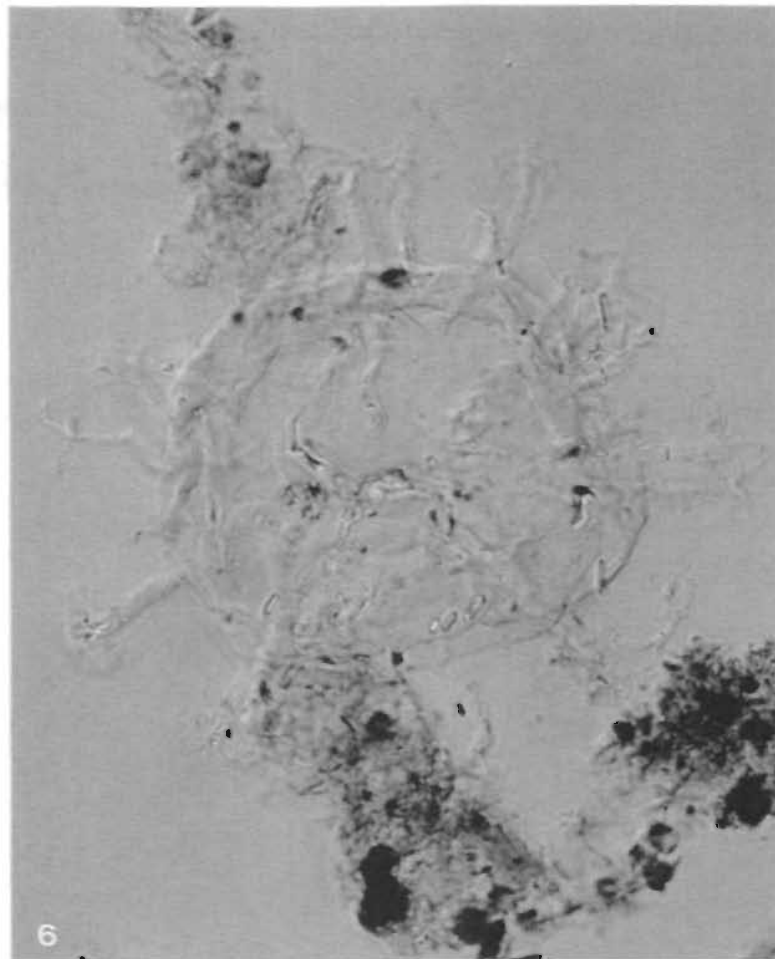
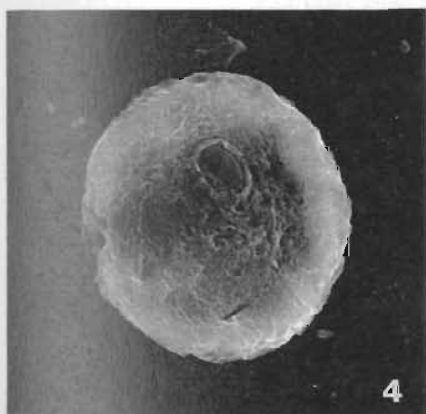
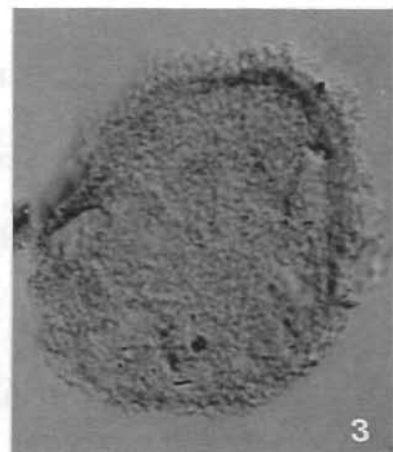
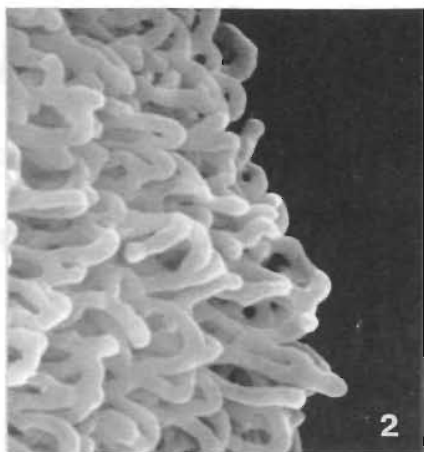
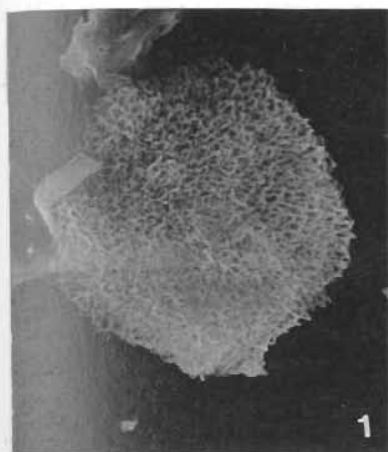


**PLATE 4**

- 1-3    ?*Comasphaeridium* sp. C. 1: P97057 <33µm, D1, x920; 2: P97057 <33µm, x6500, higher magnification of fig. 1 showing detail surface ornament; 3: P95285 1/3 siev, C37/3, x1135.
- 4, 5    *Dicommopalla macadamii* Loeblich 1970b. 4: P97057 <33µm, N2, x700, showing operculum. 5: P95434 1/2 siev, S45/2, x1135; this specimen has an operculum (see arrow on illustration).
- 6        *Excultibrachium concinnum* Loeblich and Tappan 1978, P95191 1-unox, P36/4, x1134.



PLATE 4

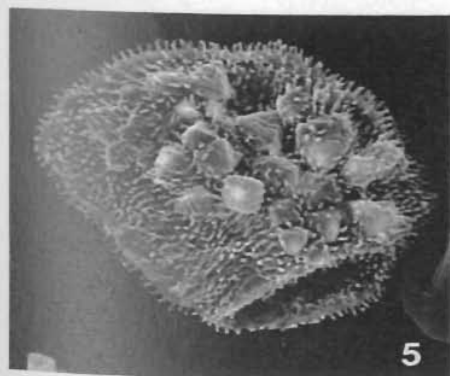
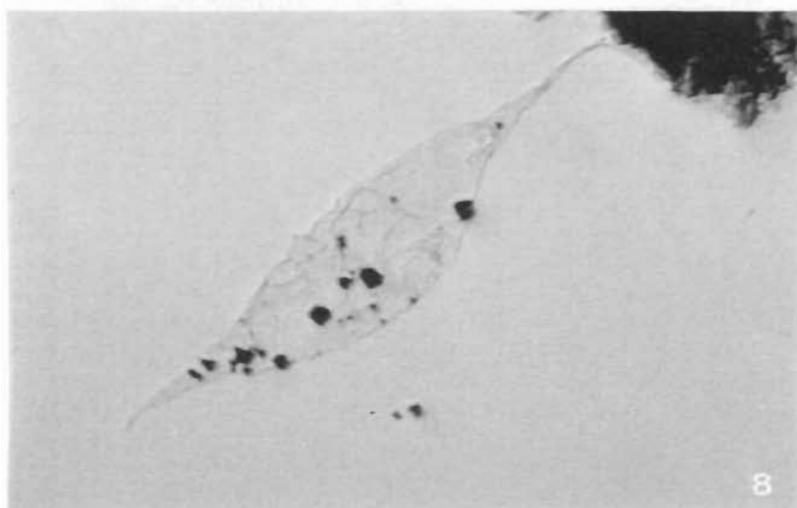
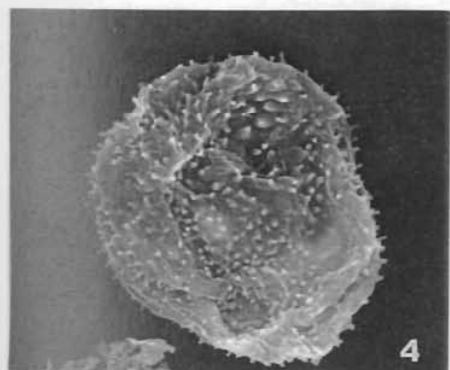
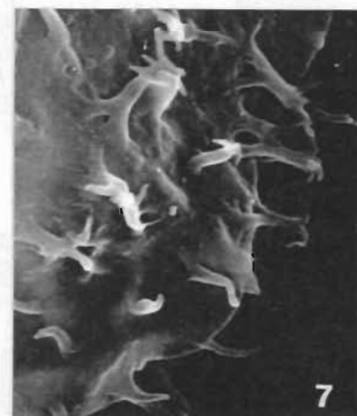
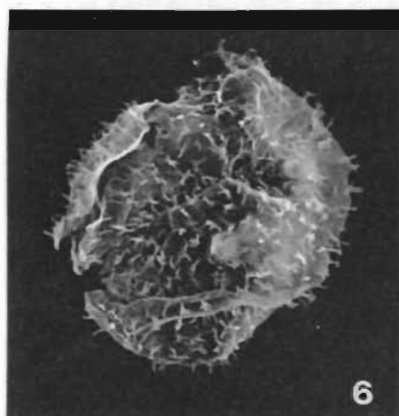
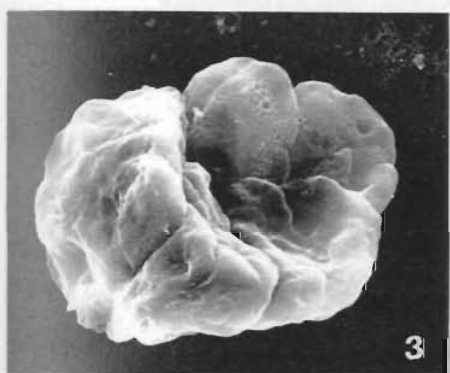
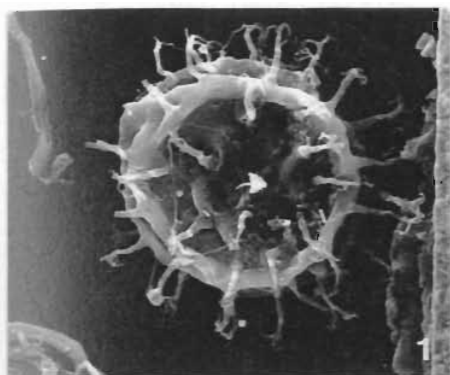




**PLATE 5**

- 1      *Excultibrachium concinnum* Loeblich and Tappan 1978, P97060 <33µm, L4, x540, showing the thread like pinnulae that extends back onto the vesicle.
- 2, 3    *Gloeocapsomorpha* sp. 2: P95288 3/3 siev, Q32/3, x 1135; 3: P97058 <33µm, L5, x1080.
- 4, 5    *Gorgonisphaeridium* sp. A. 4: P97057 <33µm, S3, x1080; 5: P97057 <33µm, E7, x1080.
- 6, 7    *Gorgonisphaeridium* sp. B. 6: P97058 >33µm, D4, x700; 7: P97058 >33µm, D4, x3770, higher magnification of fig. 7 showing detail of processes which furcate in a root like manner at their bases.
- 8      *Leiofusa fusiformis* (Eisenack) Eisenack 1938a, P95287 3/3 siev, F39/0, x720.

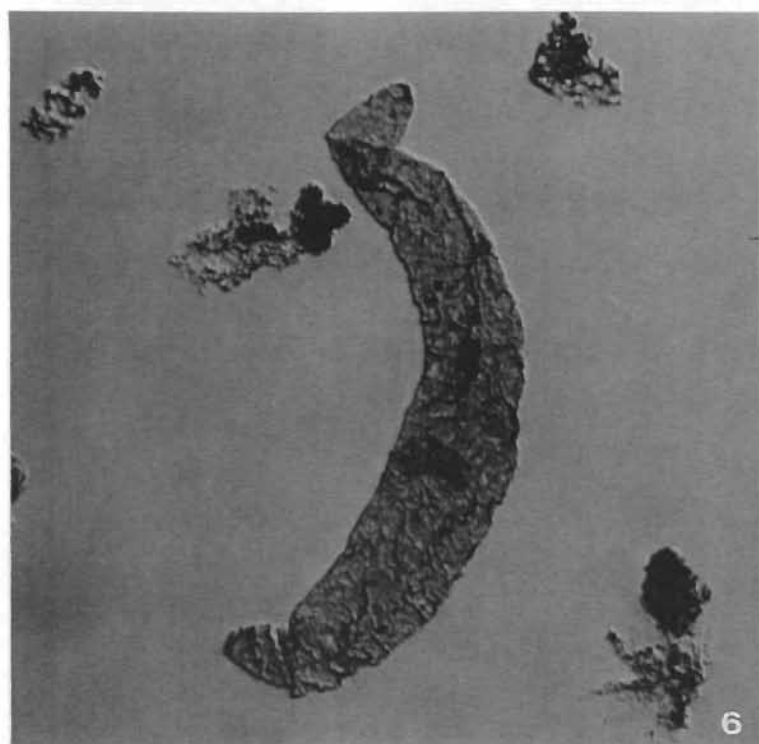
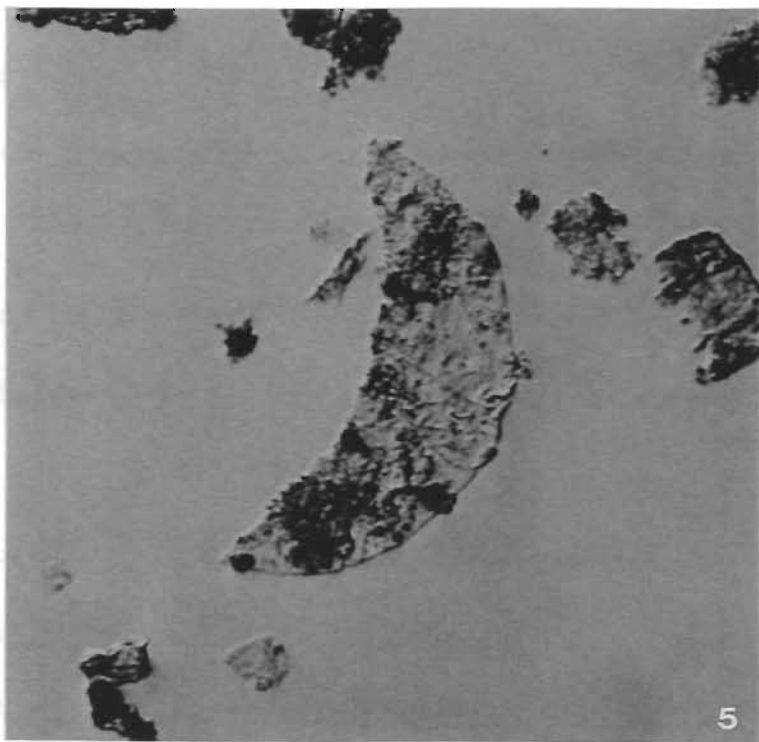
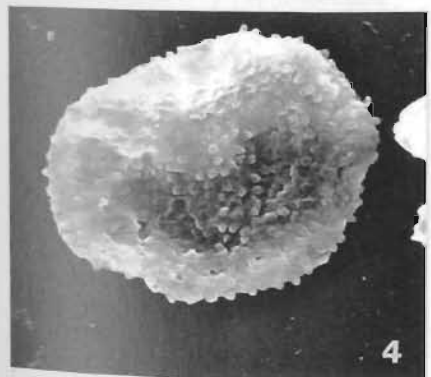
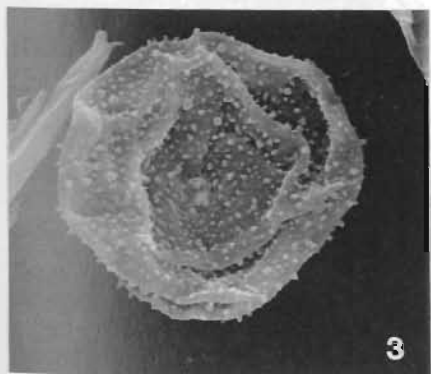
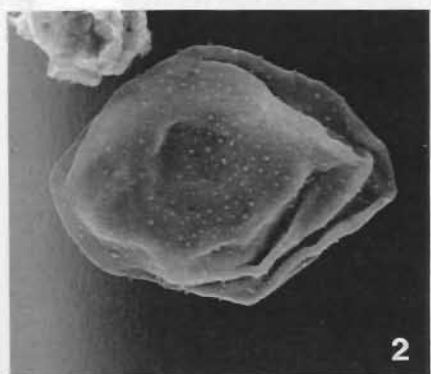
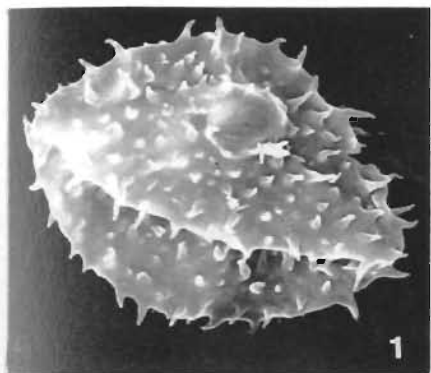
PLATE 5



**PLATE 6**

- 1     *Lophosphaeridium aequicuspdatum* Playford and Martin 1984, P970025 <21µm, x1350. No coordinates available.
- 2     *Lophosphaeridium edenense* Loeblich and Tappan 1978, P97057 <33µm, D2, x1350.
- 3     *Lophosphaeridium papillatum* Staplin (Martin 1969), P97057 <33µm, L9, x1620.
- 4     *Lophosphaeridium papulatum* Martin 1983, P97057 <33µm, D4, x1080.
- 5     *Lumulidia* sp. A, P95437 1/2 oxid, T41/0, x285.
- 6     *Lumulidia* sp. B, P95288 3/3 siev, Q35/1, x285.

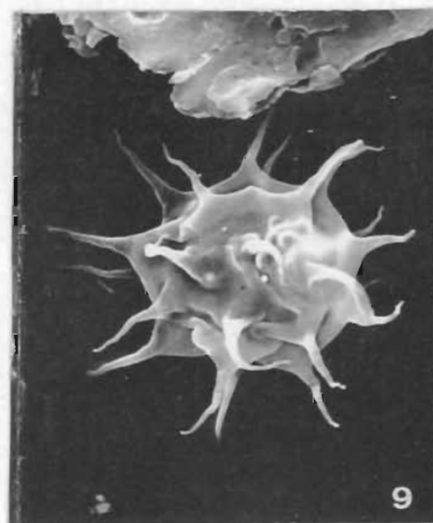
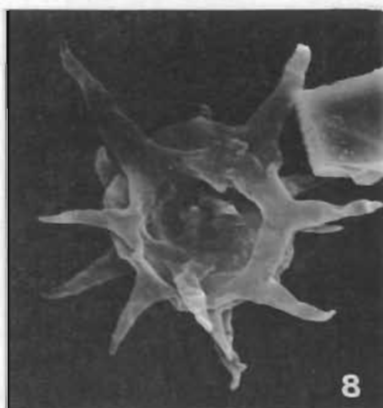
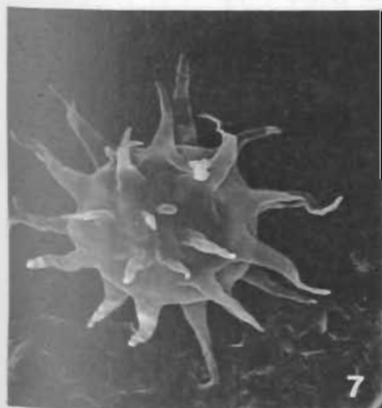
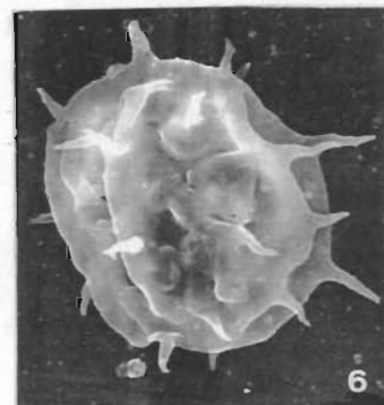
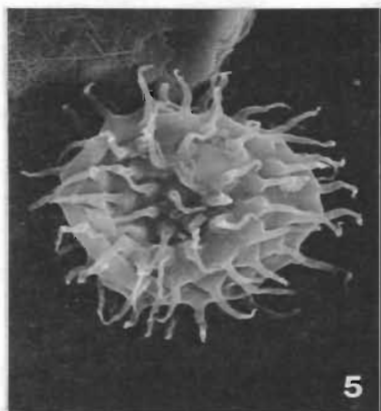
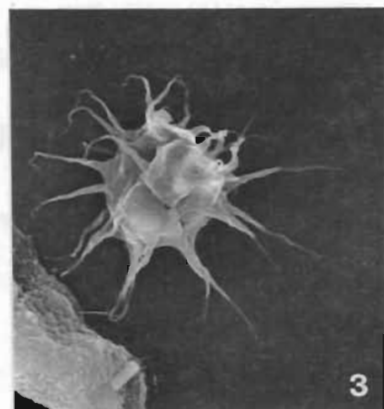
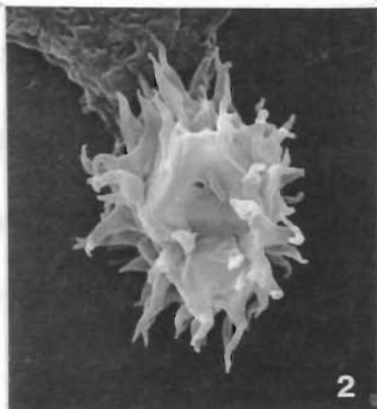
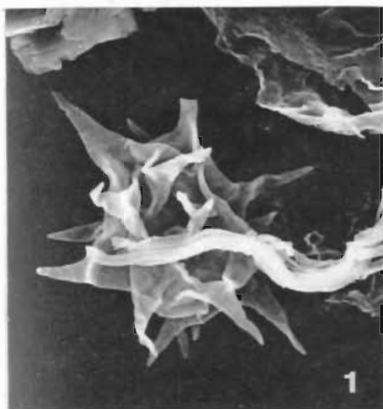
PLATE 6



**PLATE 7**

- 1     *Micrhystridium acuminosum* Cramer and Díez 1977, P97057 <33µm, G1, x1620.
- 2     *Micrhystridium aremoricum* (Paris and Deunff ) Fensome et al., 1990, P97057  
      <33µm, I10, x2160.
- 3     *Micrhystridium equispinosum* Turner 1984, P97057 <33µm, F2, x1350.
- 4     *Micrhystridium fragile* Deflandre 1947, P97025 <21µm, x1350. No coordinates  
      available.
- 5     *Micrhystridium shinetonense* Downie 1958, P97057 <33µm, G1, x1620.
- 6     *Micrhystridium* sp. A, P97025 <21µm, x1800. No coordinates available.
- 7, 8   *Micrhystridium* sp. B. 7: P97057 <33µm, Q1, x1080; 8: P97057 <33µm, J7, x1350.
- 9     *Micrhystridium* sp. C, P97025 >33µm, x900. No coordinates available.

PLATE 7

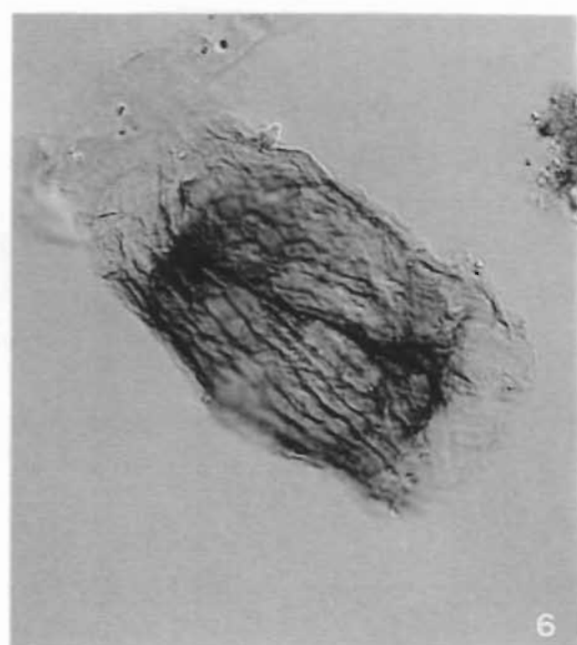
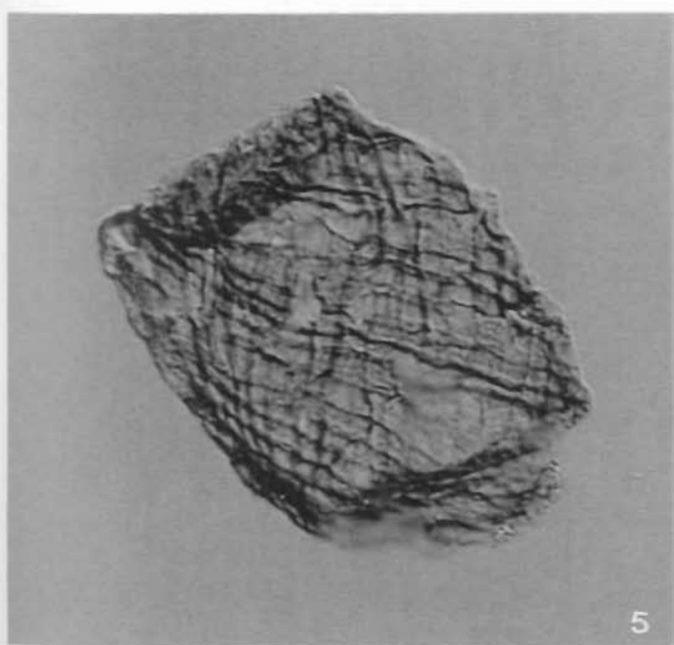
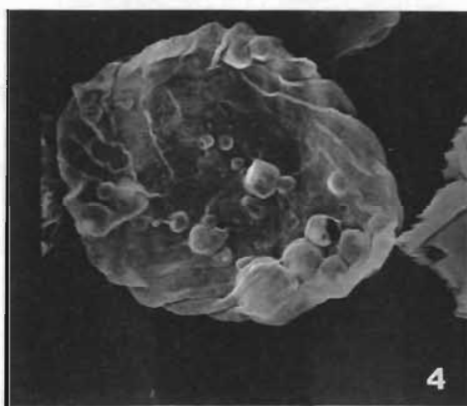
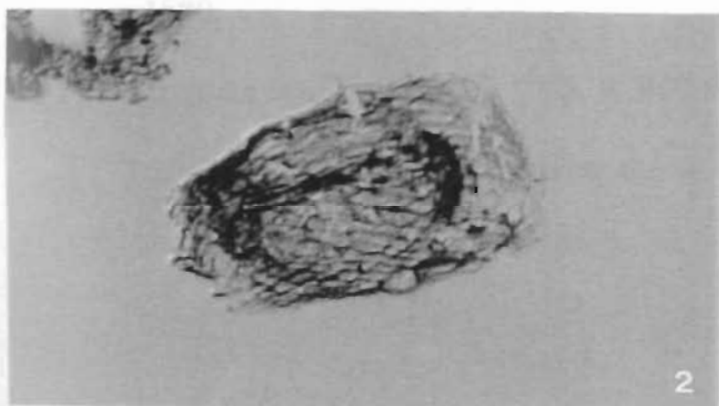
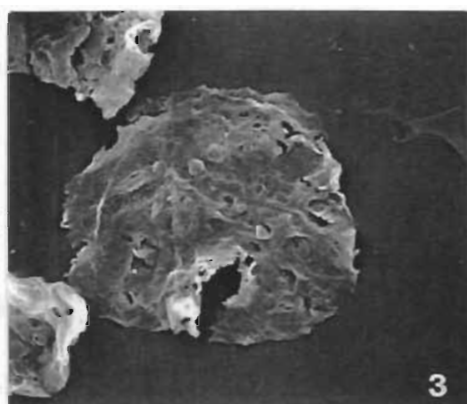
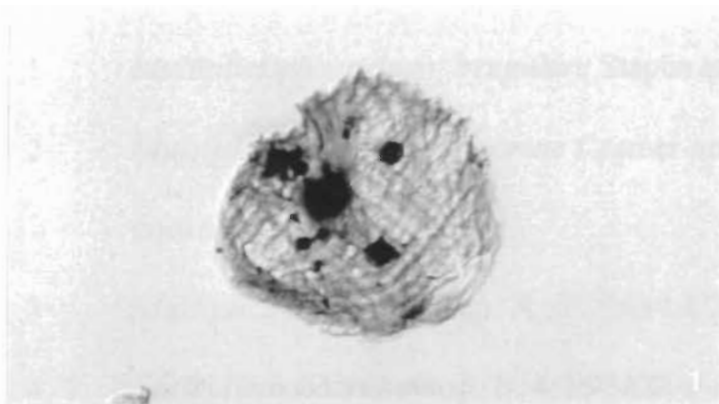


**PLATE 8**

1-6 *Moyeria cabottii* Cramer 1970. 1: P95287 3/3 siev, K44/3, x720; 2: P95287 3/3 siev, K34, x720; 3: P97057 <33µm, N4, x1080; 4: P97057 <33µm, T1, x700, 5: P95434 1/2 siev, U46/0, x1135, showing a veil like envelope. 6: P95434 1/2 siev, M63/1, x1135.



PLATE 8

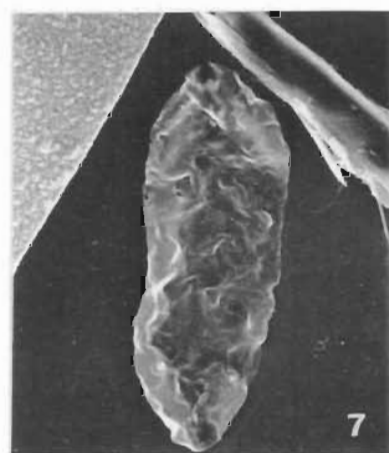
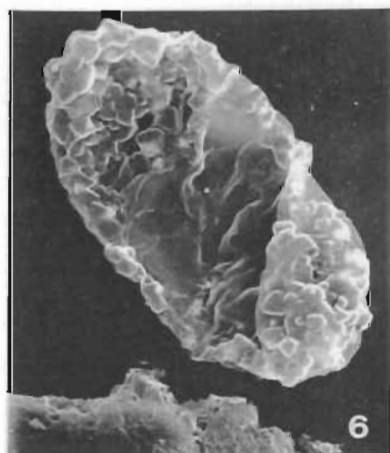
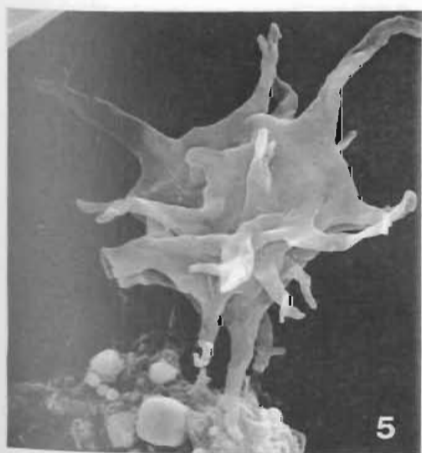
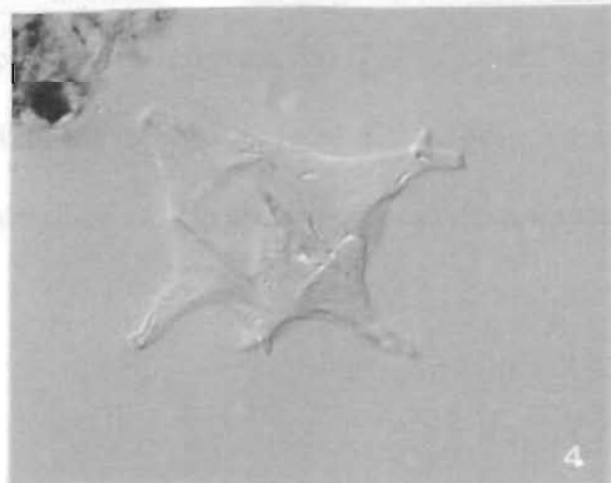
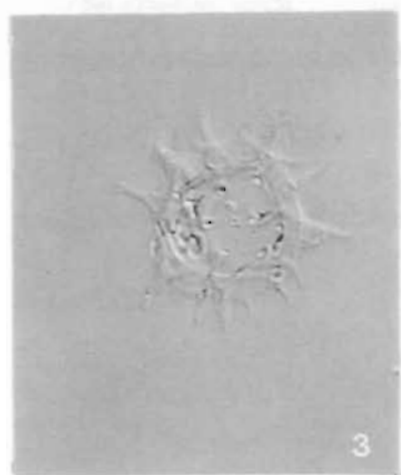
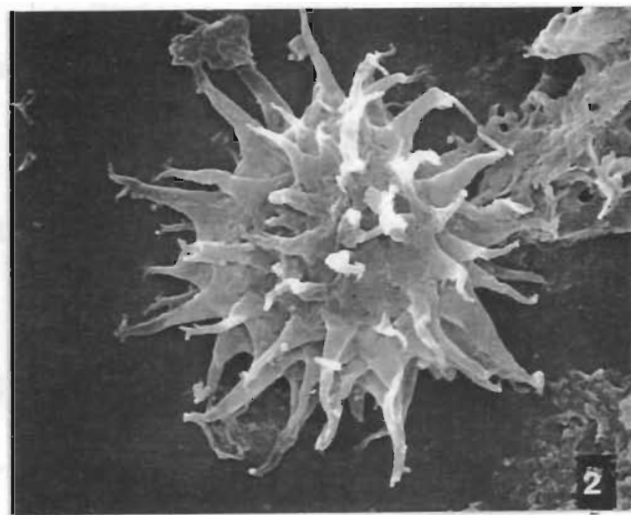
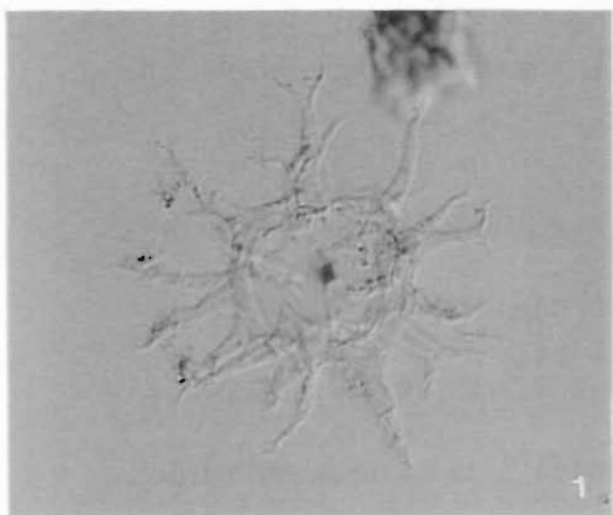




**PLATE 9**

- 1     *Multiplicisphaeridium irregulare* Staplin et al. 1965, P95284 2/3 siev, F56/3, x1135.
- 2     *Multiplicisphaeridium martae* Cramer and Díez 1972, P97025 <21µm, x2250, no coordinates available.
- 3     *Multiplicisphaeridium* sp. A, P95434 1/2 siev, S46/0, x1135.
- 4, 5   *Multiplicisphaeridium* sp. B. 4: P95272 1 unox, F58/3, x1445; 5: P97061 <33µm, F4, x1880.
- 6, 7   *Navifusa similis* Eisenack 1965. 6: P97057 >33µm, B2, x540; 7: P97057 >33µm, E1, x375. Pyrite infestation giving the illustrations a false knobby appearance.

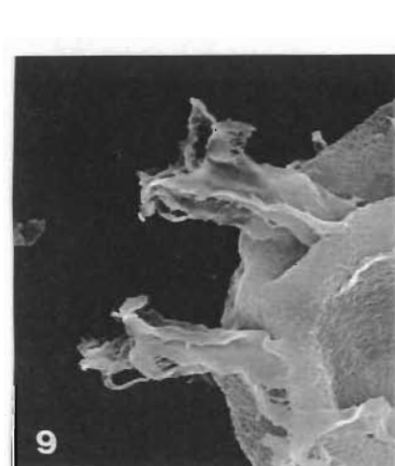
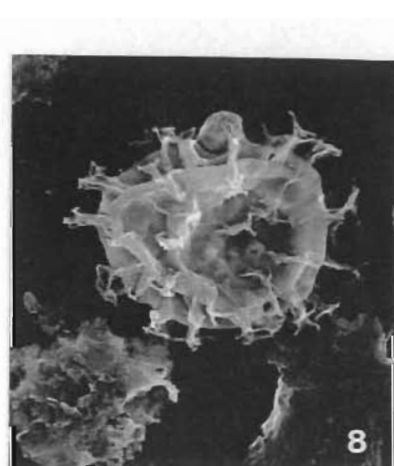
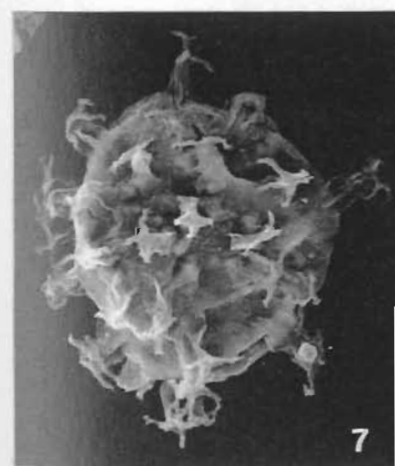
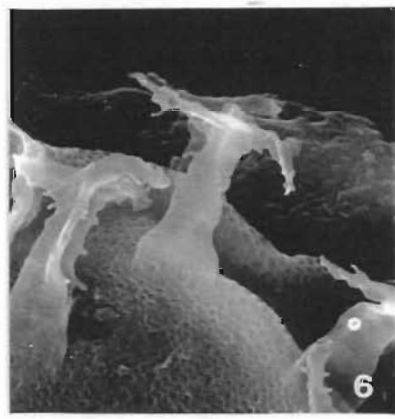
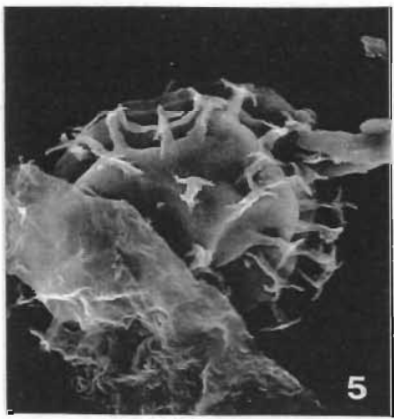
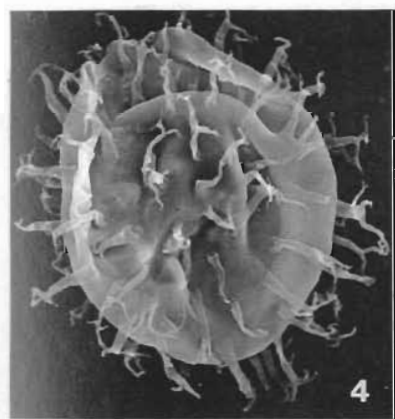
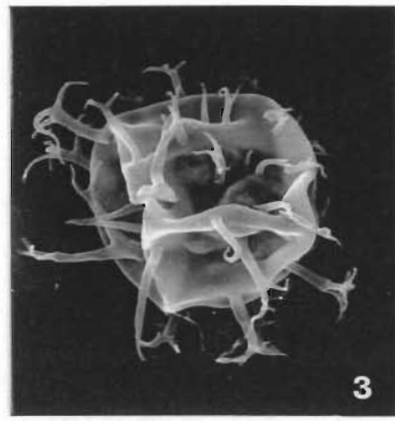
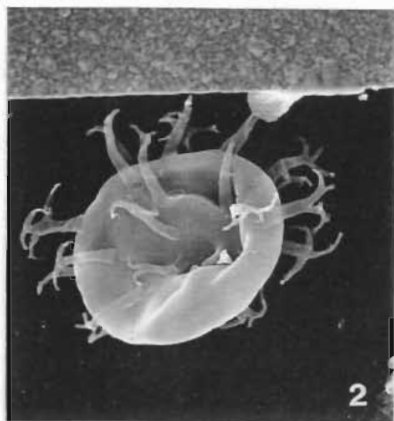
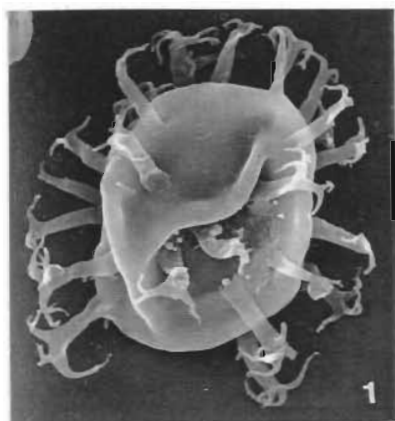
# PLATE 9



## PLATE 10

- 1      *Ordoviciidium groetlingboenis* (Kjellström) Loeblich and Tappan 1978, P97059  
          >33 $\mu$ m, R2, x5402.
- 2, 3    *Ordoviciidium heteromorphicum* (Kjellström) Loeblich and Tappan 1978. 2: P97059  
          >33 $\mu$ m, P8, x425; 3: P97058 >33 $\mu$ m, K10, x650.
- 4      *Ordoviciidium* sp., P97059 >33 $\mu$ m, F5, x700.
- 5-9    *Polyancistrodorus* sp. cf. *P. columbariferus* Loeblich and Tappan 1969. 5: P97058  
          >33 $\mu$ m, J6, x600; 6: P97058 >33  $\mu$ m, J6, x2700, higher magnification of fig. 5.  
          showing surface detail of vesicle and processes which furcate 3x. 7: P97059 >33 $\mu$ m,  
          L7, x650. 8:    P97059 >33 $\mu$ m, K5, x425; 9: P97059 >33 $\mu$ m, K5, x1880, higher  
          magnification of fig. 8 showing surface detail of vesicle and processes which furcate  
          4 times.

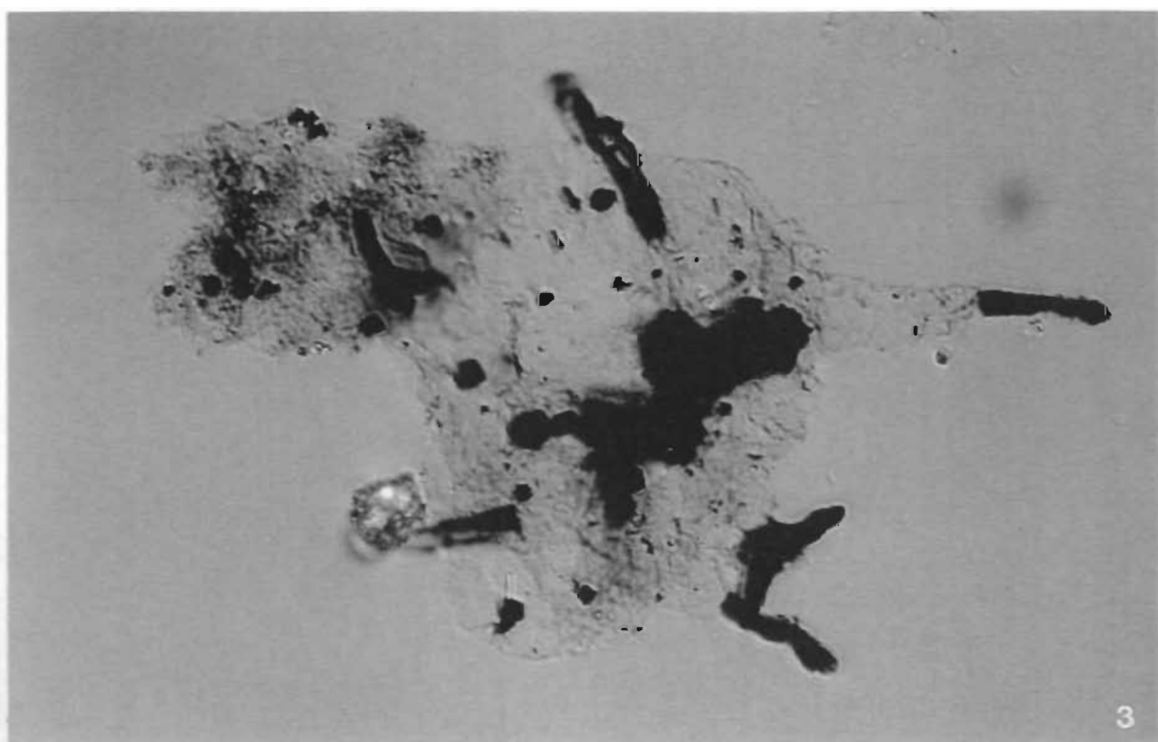
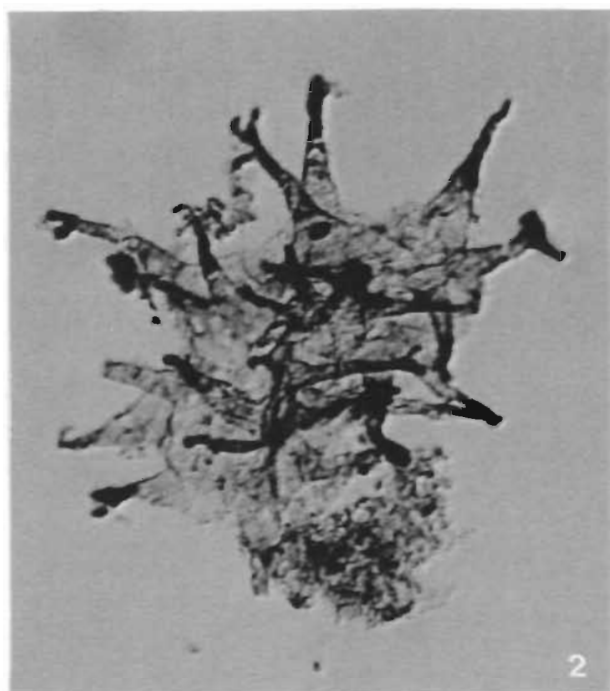
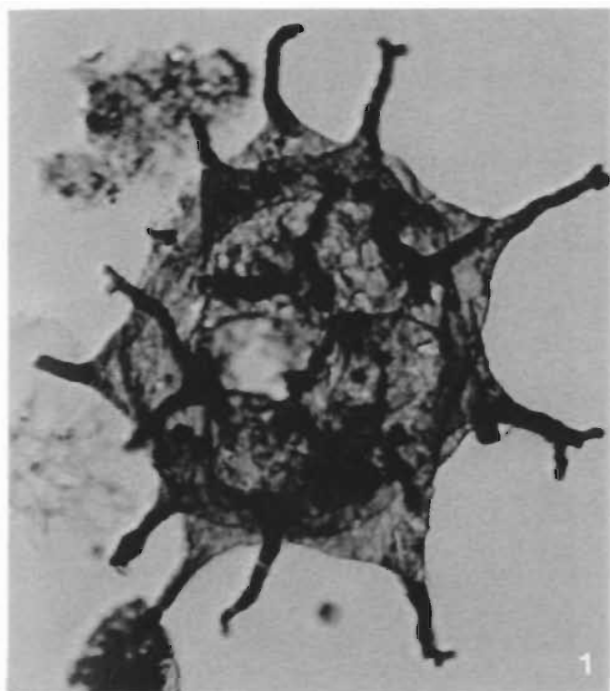
PLATE 10



**PLATE 11**

- 1-3    *Petaloferidium stigi*i Jacobson 1978a. 1: P95287 3/3 siev, J36/2, x720; 2: P95287 3/3 siev, L42/4, x720; 3: P95285 1/3 siev, T46/0, x1135.

PLATE 11

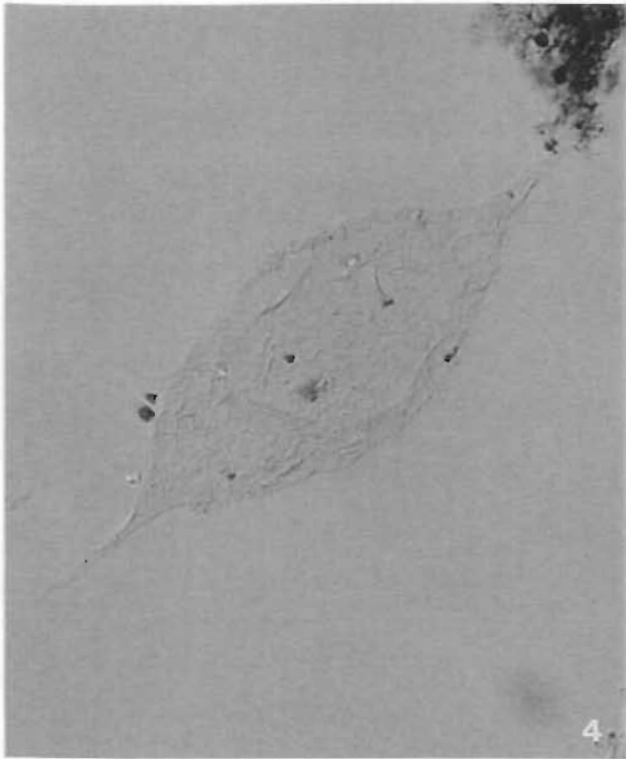
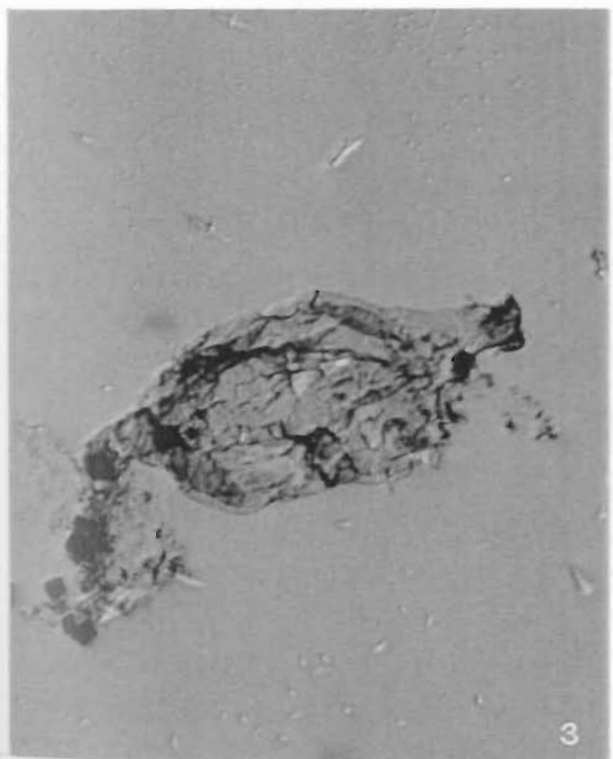
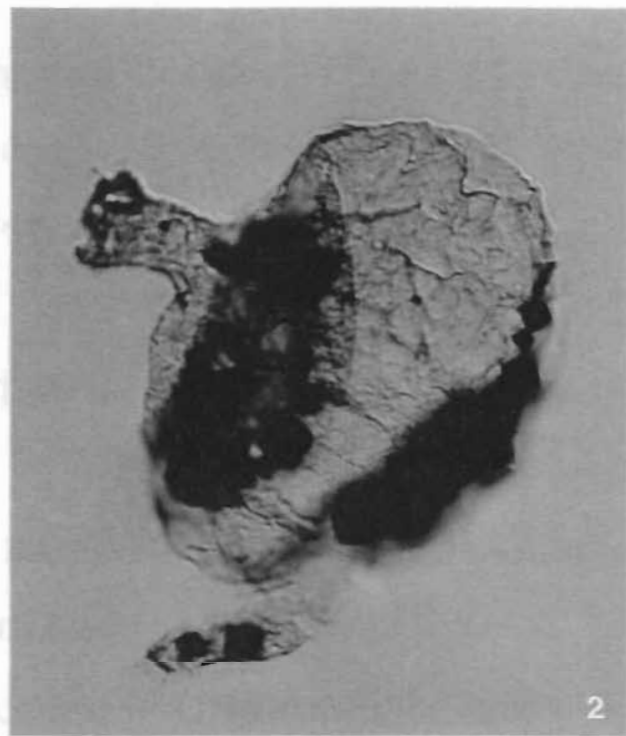
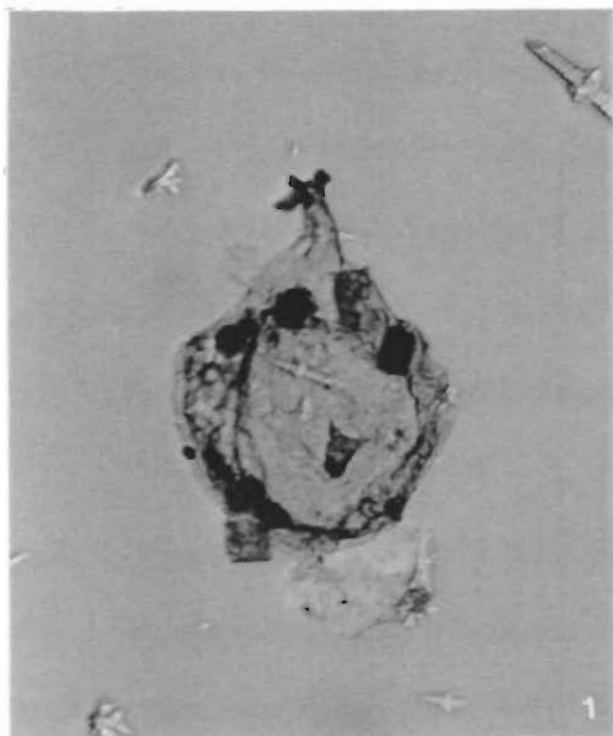


**PLATE 12**

- 1-3    *Petaloferidium* sp. 1: P95286 3/3 siev, P36/2, x720; 2: P95288 3/3 siev, K41/0, x1135; 3: P95286 3/3 siev, N46/3, x720.
- 4      *Poikilofusa* sp. cf. *P. spinata* Staplin et al. 1965, P95284 2/3 siev, D39/0, x1135.



PLATE 12

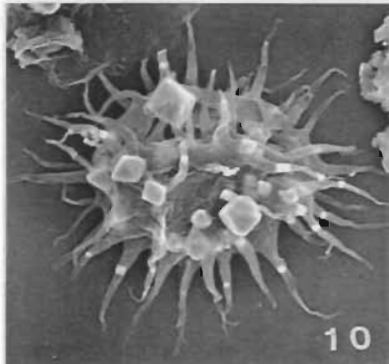
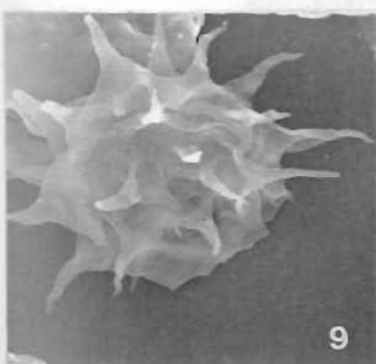
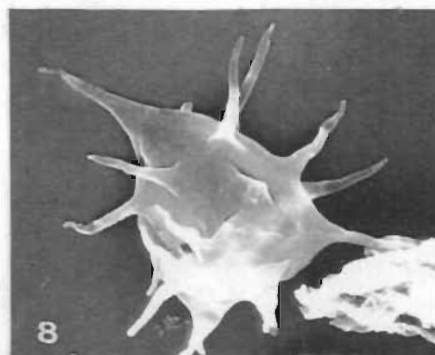
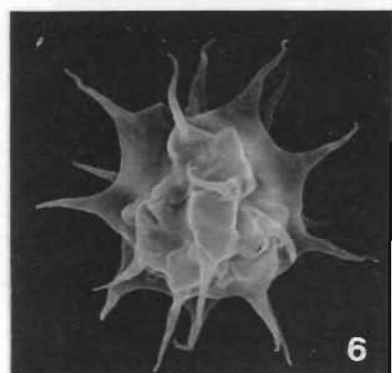
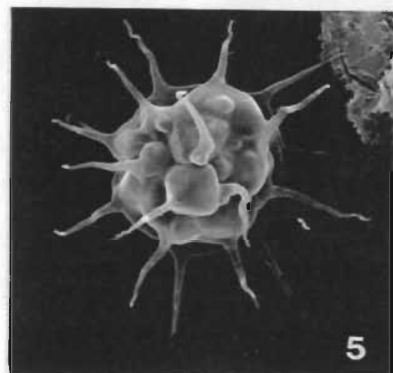
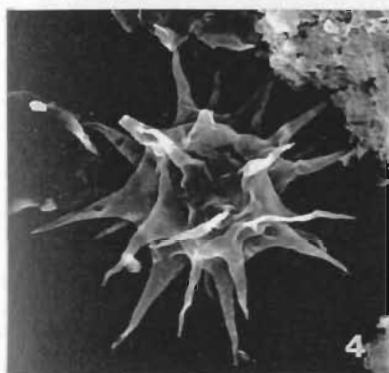
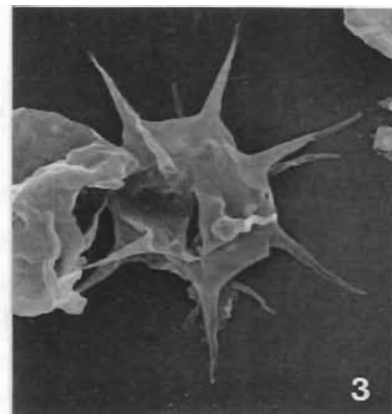
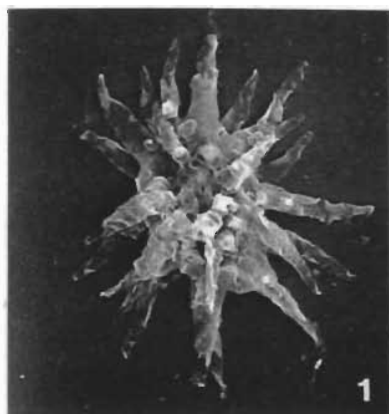




**PLATE 13**

- 1, 2 *Polygonium connectum* (Kjellström) Sargent and Stancliffe 1994. 1: P97057 >33µm, M6, x425; 2: P97059 >33µm, K1, x540.
- 3, 4 *Polygonium gracile* Vardová 1966. 3: P97057 <33µm, D8, x920, showing marginal split; 4: P97058 >33µm, D4, x540.
- 5, 6 *Polygonium tenuispinosum* Uutela and Tynni 1991. 5: P97057 >33µm, C2, x920; 6: P97059 >33µm, G1, x920.
- 7, 8 *Polygonium* sp. A. 7: P97058 >33µm, D2, x600; 8: P97057 <33µm, Q4, x1080.
- 9 *Polygonium* sp. B, P97059 >33µm, M3, x650.
- 10, 11 *Polygonium* sp. C, 10: P97059 >33µm, D2, x650; 11: P97057 >33µm, x540.

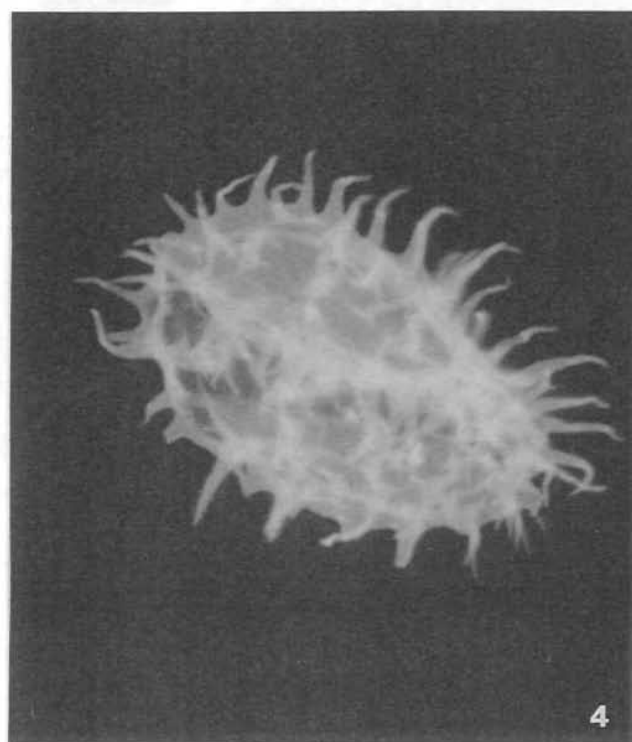
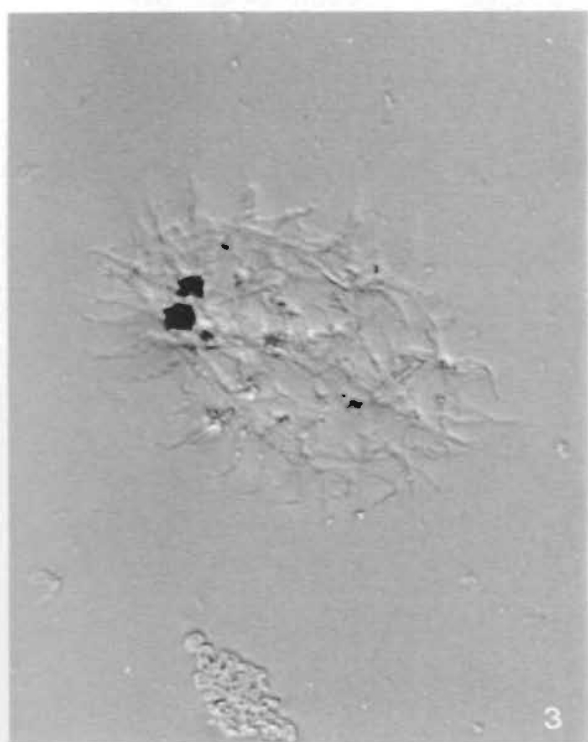
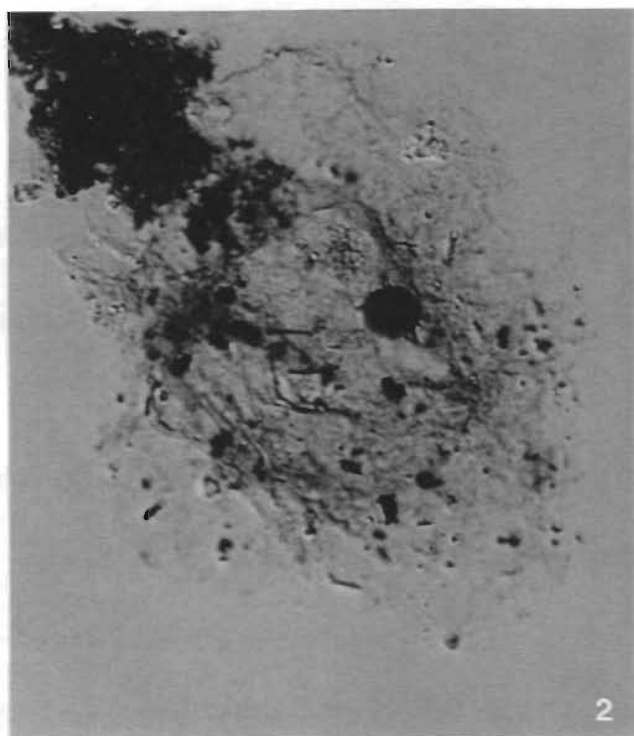
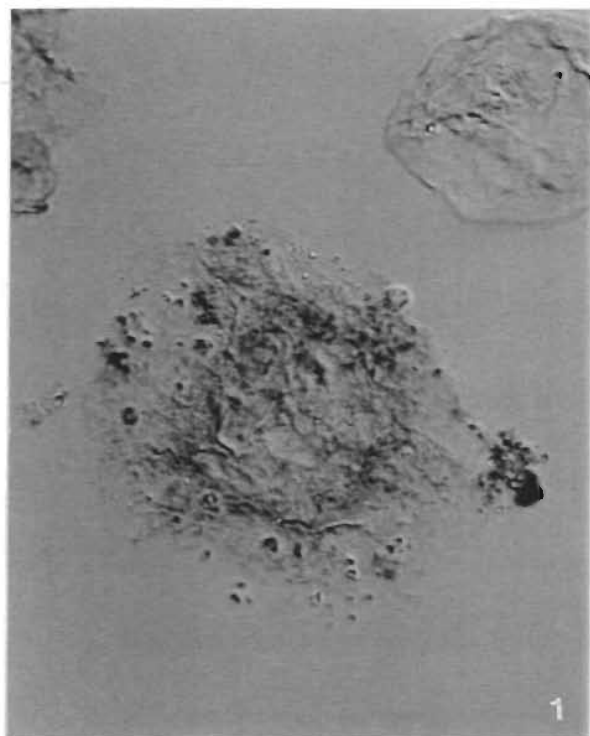
PLATE 13



**PLATE 14**

- 1, 2    *Pterospermella* sp. 1: P95434 1/2 siev, H54/4, x1135; 2: P95436 2/2 siev, U56/3, x1135.
- 3, 4    *Rhachosoarium lappaceum* Tappan and Loeblich 1971. 3: P95272 1 unox, K33/0, x720; 4: P95272 1 unox, K33/0, x1135. Fig. 3 picture is taken in regular transmitted light, whereas Fig. 4 is taken in fluorescent light.

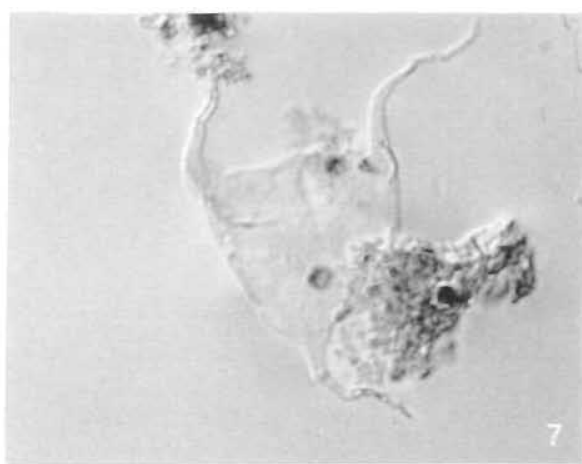
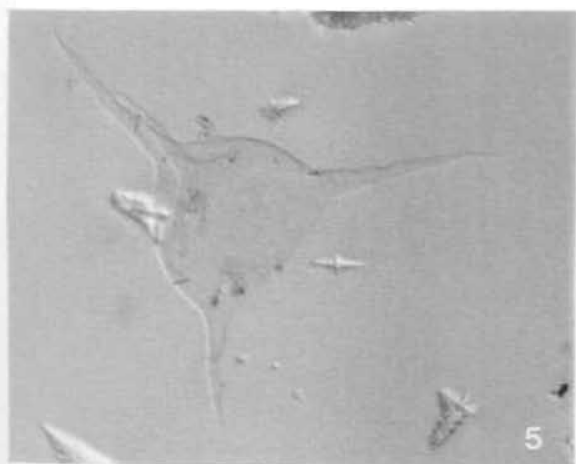
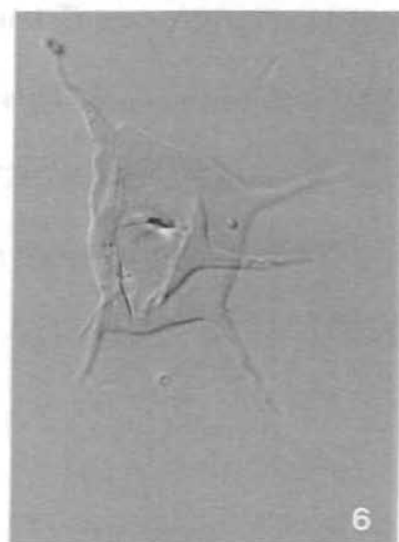
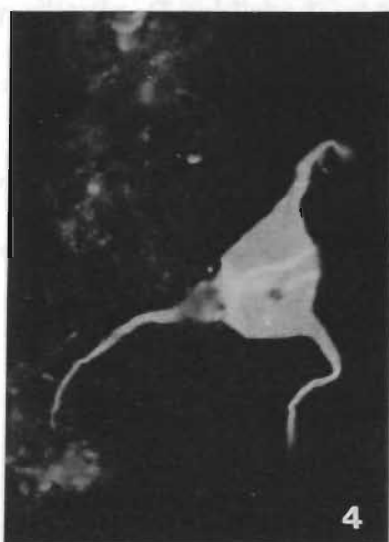
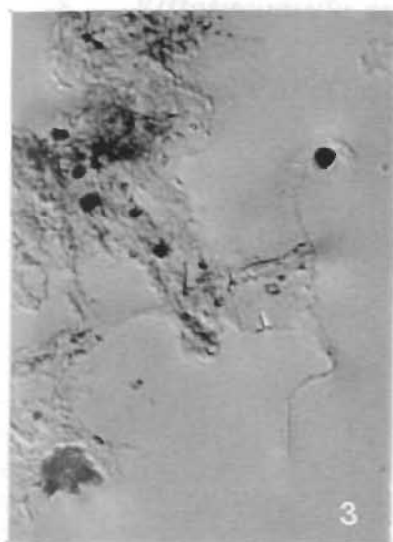
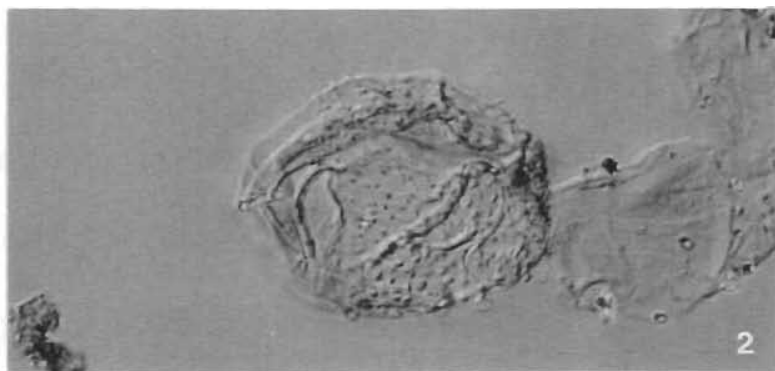
PLATE 14



## PLATE 15

- 1, 2    *Uranidium semicalvum* Jacobson and Achab 1985. 1: P97058 >33 $\mu$ m, O8, x1190.  
2: P95287 3/3 siev, G50/4, x1135.
- 3, 4    *Veryhachium downiei* Stockmans and Willière 1962. 3: P95266 1 unox, L51/1, x720;  
4: P95266 1 unox, L51/1, x720. Fig.3 is taken in regular transmitted light, where as  
Fig. 4 is taken in fluorescent light.
- 5        *Villosacapsula irroratum* (Loeblich and Tappan) Fensome et al. 1990, P955286 3/3  
siev, P49/4, x720.
- 6        *Veryhachium rhomboidium* Downie 1959, P95434 1/2 siev, G44/2, x1135.
- 7        *Veryhachium trispinosum* (Eisenack) Stockmans and Willière 1962, P95266 1 unox,  
Q31/2, x720.

PLATE 15

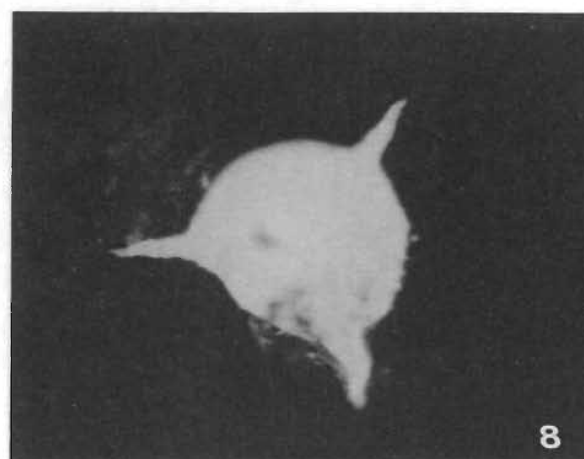
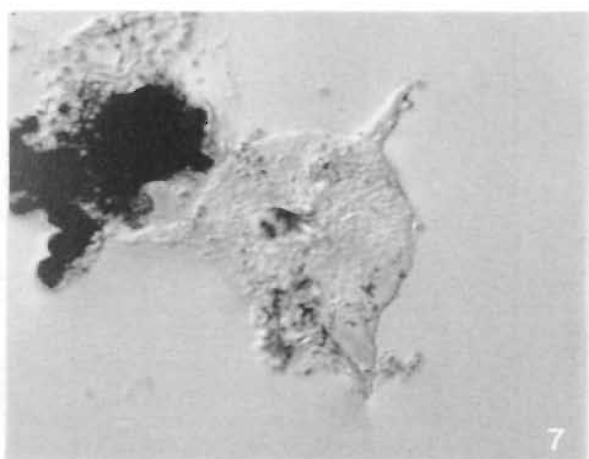
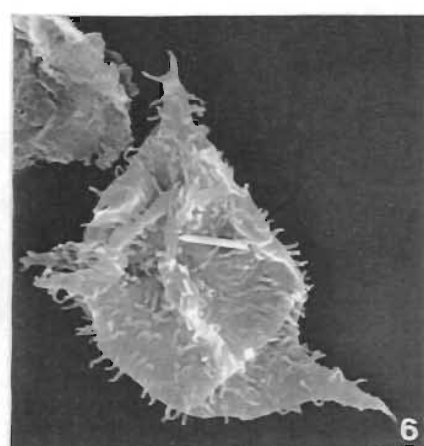
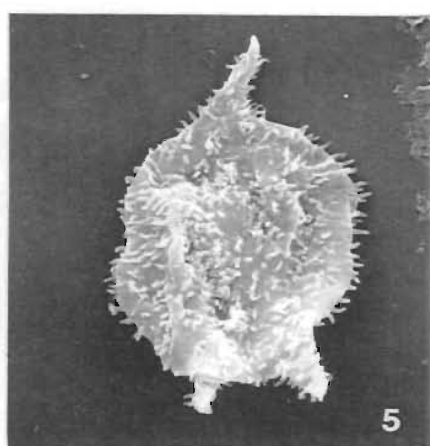
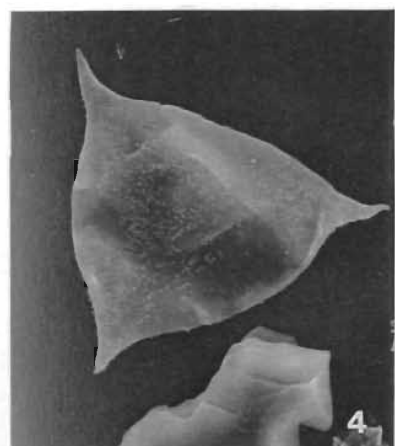
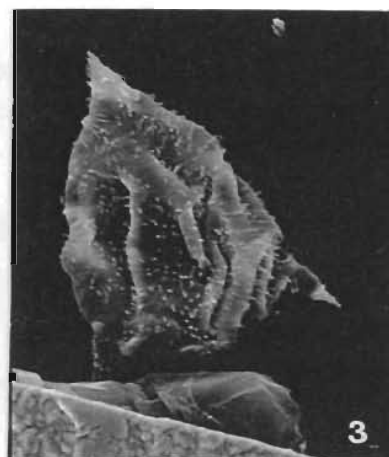
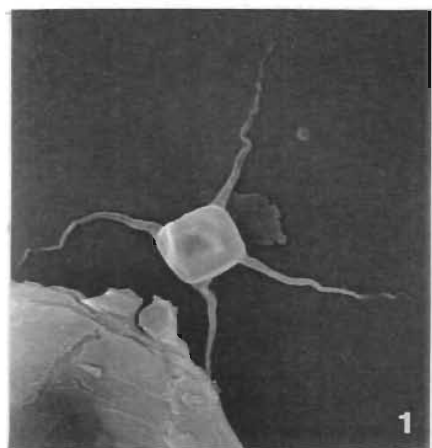


## PLATE 16

- 1     *Veryhachium oklahomense* Loeblich 1970a, P97057 <33 $\mu$ m, H8, x1190.
- 2     *Veryhachium valiente* Cramer 1964, P97059 >33 $\mu$ m, C5, x1350.
- 3, 4   *Villosacapsula entrichos* (Loeblich) Loeblich and Tappan 1976. 3: P97058 <33 $\mu$ m, I1, x1080, showing slightly longer ornament than specimen in fig. 4; 4: P97057 <33 $\mu$ m, F3, x1350.
- 5-8   *Villosacapsula setosapellicula* (Loeblich) Loeblich and Tappan 1976. 5: P97060 <33 $\mu$ m, E6, x1190; 6: P97060 <33  $\mu$ m, J3, x1190, showing four processes, 7: P95367 1/2 siev, H30/0, x720; 8: P95367 1/2 siev, H30/0, x720. Fig. 6 is taken in regular transmitted light, whereas Fig. 7 is taken in fluorescent light.



PLATE 16

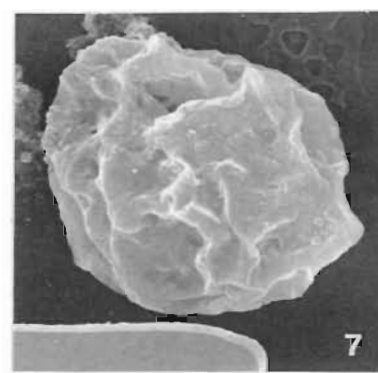
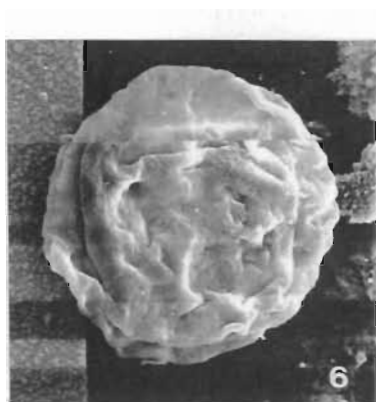
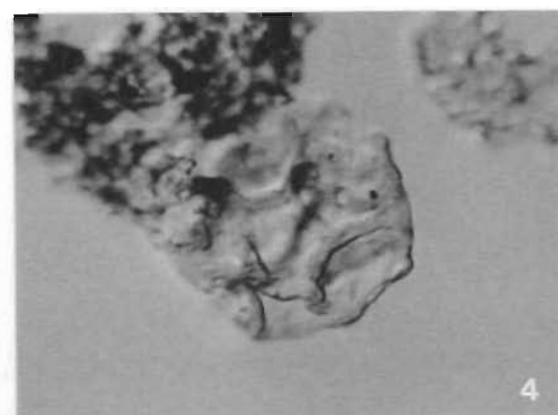
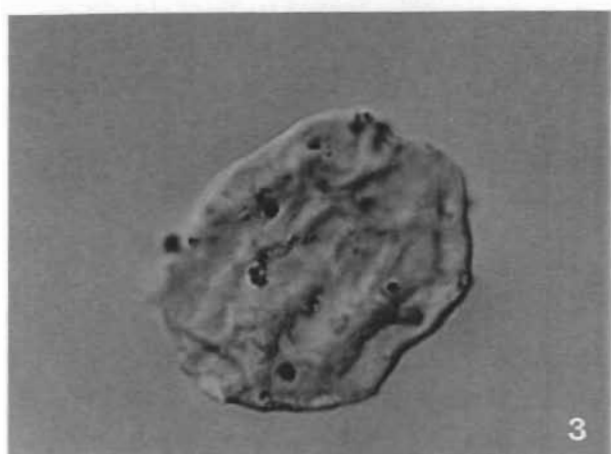
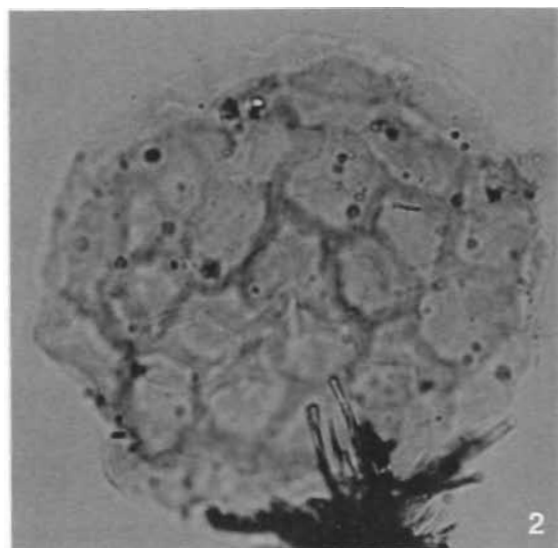
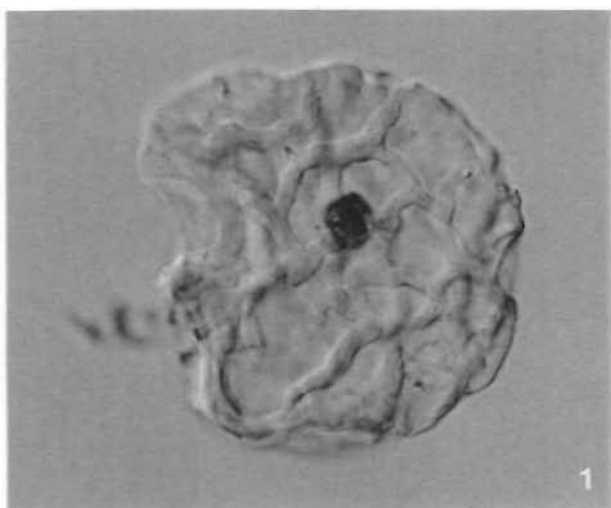




**PLATE 17**

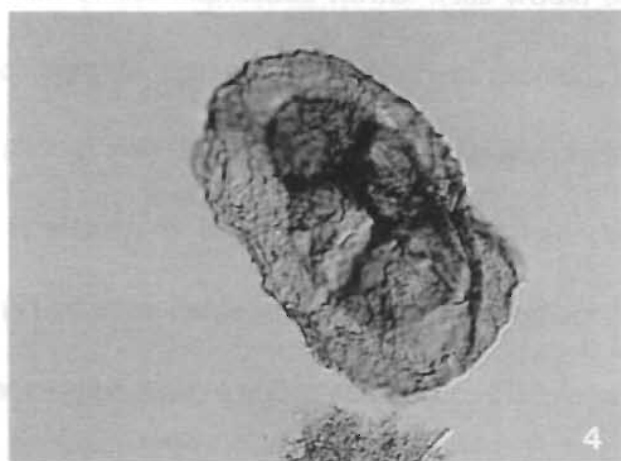
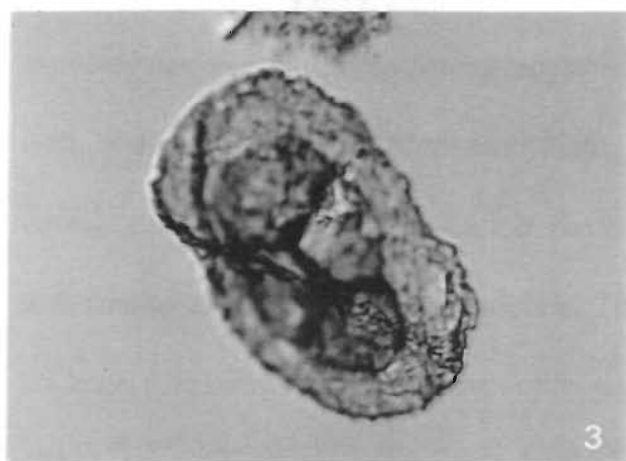
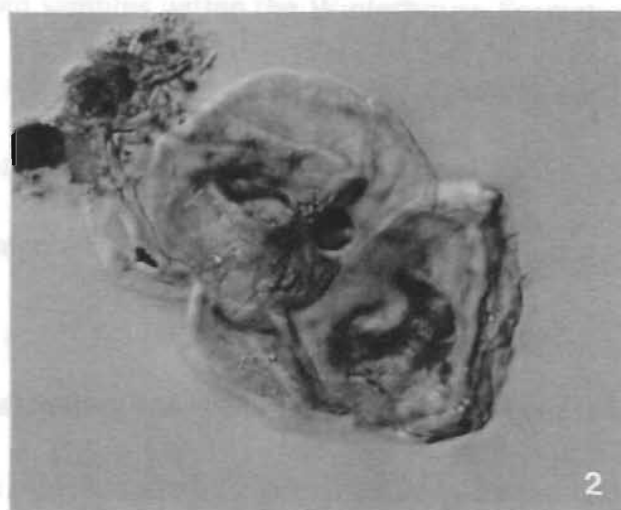
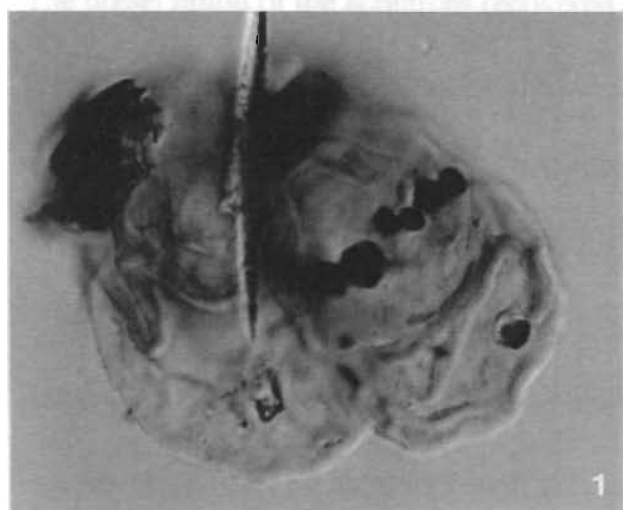
- 1, 2 *Cymatiosphaera* sp. A, 1: P95284 2/3 siev, D41/4, x1135; 2: P97025 1/2 unox, F60/4, x1135.
- 3, 4 *Cymatiosphaera* sp. B, 3: P95287 3/3 siev, M50/1, x1135; 4: P95286 3/3 siev, U42/3, x720.
- 5-7 *Leiosphaeridia* sp., 5: P97058 >33 $\mu$ m, S3, x540; 6: P97060 >33 $\mu$ m, G4, x325; 7: P97061 >33 $\mu$ m, F5, x270.

PLATE 17



**PLATE 18**

- 1, 2    Cryptospore sp. A. 1: P95286 3/3 siev, M33/3, x1135; 2: P95434 1/2 siev, D48/4, x1135.
- 3-6    Cryptospore sp. B. 3: P95434 1/2 siev, U48/0, x1135; 4: P95434 1/2 siev, U48/0, x1135, same as fig. 3 focusing through the specimen showing fold on the underside; 5: P95434 1/2 siev, D44/2, x1135; 6: P95434 1/2 siev, R47/4, x1135.



### **3.4: FOSSIL MATURITY LEVELS**

The preservation of the acritarchs recovered from samples within the Winterhouse Formation is very good, only a few genera found in the uppermost part of the river section appear to show any signs of degradation. This state of preservation is no doubt related to the low overall degree of thermal maturation, complimented by the environment of deposition.

A few empirical observations regarding thermal maturation were made during the course of this investigation. Specimens which are large, thick-walled, or ornamented were typically darker in overall appearance than the small, thin or unornamented forms. This would be expected since each of these parameters would change the density or chemistry of the vesicle wall, and hence its ability to transmit light. It should also be noted here, that the acritarchs within the Winterhouse Formation have a tendency to be lighter in colour than the surrounding unstructured organic debris. This is understandable since acritarchs, in general, are known to behave differently than other palynomorphs such as pollen and spores (Traverse, 1988).

Acritarchs, as well as other organic constituents in sediments, change their organic composition as they become buried and subjected to geothermal gradients within the earth's crust. This change in organic composition by geothermal processes is known as thermal maturation. The amount of thermal maturation that acritarchs have undergone during their depositional history can be estimated by their colour as seen through a transmitted light

microscope using either regular transmitted or fluorescent light sources. In general, as temperature or oxidation processes increase, acritarchs alter in colour from essentially clear and colourless to black. Depending on its colour, organic matter is described as immature, mature or post mature, each of which reflect stages in the organic maturation process: diagenesis, catagenesis and metagenesis (Dow, 1977; Staplin, 1982). Each stage has a specific temperature range, and each results in different colour acritarchs.

A total of 14 samples were analysed for thermal maturity: eleven from the Shore section and three from the River section. The acritarch alteration index (AAI) methodology used in this study follows that of Williams et al., (in press.). Sampling was spaced evenly throughout the composite section.

The average AAI of the acritarch genera within the Winterhouse Formation in transmitted light (tran) is  $1.6 \pm 0.3$ , which is a pale yellow in colour; the average AAI in fluorescent light (fluor) is  $1.6 \pm 0.2$ , which is bright yellow to white. These indices, when compared to AAIs of Williams et al., (in press.), indicate that the samples have undergone very little temperature change, are immature in their ability to generate oil, and therefore not within the oil window.

There is a significant increase in the AAI values of the acritarch population from the bottom of the Winterhouse Formation, as seen in the bottom of the Shore section (tran. AAI = 1.2, fluor. AAI = 1.5), towards the top of the Winterhouse Formation, as seen in the top of the

River section (trans. AAI = 2.0, fluor. AAI = 2.2) (see Table 3.1). This increase in AAI values up section is uncommon under normal depositional settings. TAI values normally increase down section because the geothermal gradient also increases with depth of burial.

Since the average AAI, of the whole acritarch population, changed up section it became necessary to investigate how individual genera were behaving with regard to AAI, to insure that no specific genus was influencing the AAI values. This investigation also assisted in determining if darker acritarchs, which appear for the first time in the upper part of the section, were reworked.

The major genera were studied separately and it was determined from the evidence presented in Table 3.2 and 3.3 that all the acritarch genera were increasing in AAI, but the trend does not appear to be statistically significant. This still did not explain why two genera *Petaloferidium* and *Moyeria* which appeared for the first time in relatively low numbers in the upper portion of the section are more corroded and darker in appearance than other species found in that part of the section. The age of *Petaloferidium stigii* and *Moyeria cahottii* appear to be penecontemporaneous with the in situ forms (Text-Figure 4.2). If they are indeed age synchronous then one possible explanation for their apparent corroded condition is that they are not indigenous to the facies in which they are found but have been leached or washed in from some other depositional environment. Another possible explanation for their apparent condition might lie in the subtle differences in their chemical

<b>ACRITARCH ALTERATION INDICES AVERAGE VALUES PER SAMPLE</b>		
<b>SAMPLE &amp; Estimated DEPTH</b>	<b>TRANSMITTED LIGHT</b>	<b>FLUORESCENT LIGHT</b>
RIVER SECTION H-5-95    2.80 cm	1.2	1.5
H-11-95    35 m	1.1	1.3
H-20-95    70 m	1.3	1.4
H-28-95    102 m	1.4	1.4
H-34-95    130 m	1.5	1.7
H-44-95    170 m	1.3	1.5
H-69-95    200 m	1.5	1.6
H-74-95    230 m	1.4	1.5
H-81-95    275 m	1.4	1.7
H-87-95    300 m	1.8	1.8
H-90-95    350 m	1.6	1.6
<i>COVERED SECTION – 500 metres</i>		
SHORE SECTION H-64-95    ~850 m	1.8	1.8
H-59-95    ~875 m	2.0	2.0
H-54-95    ~976 m	2.0	2.2
AVERAGE AAI VALUES for the WINTERHOUSE FORMATION	1.6 ± 0.3	1.6 ± 0.2

TABLE 3.1: Average acritarch alteration indices for samples at specific depths within the Winterhouse Formation, including the average overall value with standard deviation. Averages are based on a minimum of 100 counts per sample.



ACRITARCH ALTERATION INDICES FOR TRANSMITTED LIGHT														
WINTERHOUSE FORMATION    COMPOSITE SECTION														
SHORE SECTION												RIVER SECTION		
GENUS / SAMPLE	bottom H-05	H-11	H-20	H-28	H-34	H-44	H-69	H-74	H-81	H-87	top H-90	bottom H-64	middle H-59	top H-54
Gloeocapsomorpha	1.9	1.6	1.7	1.9	2.4	2.2	2.0	2.2		0.0		2.5	3.0	2.1
Baltisphaeridium		1.2			2.1				1.4	1.6	2.0	1.9	2.3	1.5
Comasphaeridium		0.9	1.3	1.2	1.3	0.8	1.4	1.3	1.5	1.5		1.6	1.6	2.0
Moyeria												3.0		2.9
Fusiform(s)	0.8	0.9	2.6	1.2	1.6	1.0			0.8	1.9	0.9			
Polygonium	1.1	1.2	1.2	1.0	1.5	1.3	1.3	1.2	1.4	2.0	2.0	1.6	2.1	1.9
Lophosphaeridium	1.5			1.2	1.5	1.2	1.6	1.3	1.5	2.0	1.9	2.1	2.3	2.1
Micrhystridium	0.9	1.0	1.2	1.1	1.3	1.3	1.3	1.2	1.2	1.4	1.3	1.9	1.8	1.9
Multiplicisphaeridium			1.2	1.5	1.7		1.2	1.4	1.4	1.8	1.8	2.7		2.3
Ordoviciidium		1.2	1.3			1.0	2.4	1.6	1.6	2.5	2.2	2.0		
Polyancistrodorus	1.6	1.6			2.0							2.4		2.4
Sphaeromorphs >50µm	2.6	0.8	2.0	1.6	2.0	1.5	1.6	1.5	1.7	2.0	1.8	1.3	2.0	
20-50µm	1.3	1.1	1.4	1.4	1.6	1.5	1.9	1.3	1.7	2.0	1.8	1.8	1.9	2.0
0-20µm	1.1	1.0	1.2	1.2	1.4	1.2	1.4	1.4	1.2	1.7	2.0	1.6	1.6	2.0
Veryhachium	1.3	1.2	1.2	1.1	1.7	1.1	1.2	1.6	1.3	1.5	1.9	2.0	2.1	1.4
Villosacapsula	0.9		1.2	1.2	1.4						2.4			

TABLE 3.2: Acritarch alteration indices for major genera of the Winterhouse Formation as seen in transmitted light.

ACRITARCH ALTERATION INDICES FOR FLUORESCENT LIGHT														
WINTERHOUSE FORMATION COMPOSITE SECTION														
GENUS / SAMPLE	SHORE SECTION											RIVER SECTION		
	bottom H-05	H-11	H-20	H-28	H-34	H-44	H-69	H-74	H-81	H-87	top H-90	bottom H-64	middle H-59	top H-54
Gloeocapsomorpha	1.5	1.8	1.7	2.0		2.2	2.0	1.9				2.5	2.6	2.3
Baltisphaeridium		1.6			2.1				1.5	1.7	1.6	2.2	2.3	1.6
Comasphaeridium		1.2	1.3	1.1	1.4	1.2	1.5	1.4	1.5	1.4		1.5	1.2	2.3
Moyeria												4.0		3.8
Fusiform(s)	1.2	1.2	1.8	1.3	1.8	1.4			1.2	2.0	2.6			
Polygonium	1.4	1.4	1.5	1.3	1.6	1.5	1.4	1.4	1.7	2.0	2.2	1.6	2.1	2.1
Lophosphaeridium	1.8			1.2	1.8	1.2	1.8	1.4	1.6	2.0	1.8	2.1	2.3	2.1
Michrhystridium	1.3	1.2	1.2	1.1	1.4	1.4	1.5	1.3	1.5	1.5	1.3	1.9	1.8	1.8
Multiplicisphaeridium			1.2	1.5	1.5		1.4	1.4	1.5	1.7	1.6	2.7		2.5
Ordoviciidum		1.2	1.3			1.4	2.6	1.6	2.0	2.6	1.9	1.6		
Polyancistrodorus	1.6	1.6			2.0							2.4		2.6
Sphaeromorphs >50µm	2.6	1.2	2.4	1.6	2.3	1.6	1.5	1.6	1.8	2.0	1.6	1.3	2.3	
20-50µm	1.7	1.3	1.5	1.5	1.7	1.7	1.9	1.5	2.0	2.0	1.8	1.8	1.9	2.2
0-20µm	1.7	1.3	1.3	1.3	1.6	1.4	1.5	1.5	1.5	1.9	1.9	1.6	2.0	1.6
Veryhachium	1.4	1.2	1.3	1.3	1.9	1.3	1.4	1.7	1.4	1.7	1.7	2.1	1.4	1.9
Villosacapsula	1.4		1.2	1.2	1.4						2.0			

TABLE 3.3: Acritarch alteration indices for major genera of the Winterhouse Formation as seen in fluorescent light.

composition when compared with other taxa (i.e. more susceptible to weathering).

The increase in thermal maturation of all genera up section may be related to two geological processes which have affected the Winterhouse Formation. First, the Winterhouse Formation is known to have undergone structural deformation. This is evident from detailed mapping which indicates the formation is locally overturned and structurally disrupted (Quinn et al., in prep.). This is particularly evident in the River section where beds are locally faulted and lie adjacent to the Round Head Thrust (Williams et al., 1995, p. 387). This type of deformation may be sufficient to either generate heat to change the AAI's of the acritarchs or, more likely, act as a conduit, for warm deeply buried hydrothermal fluids. Secondly, the Winterhouse Formation is known to represent a progradational succession from carbonate dominated offshore deposits at the base to marginal marine/deltaic deposits at the top (Quinn et al., in prep.). This change in environment may generate a geochemical explanation in that shallow oxidizing environments can potentially alter in a subtle manner the acritarch alteration index by being more corrosive in nature. The fact that the Winterhouse Formation is locally overlain and progrades into coarser red sandstone beds of the newly named Misty Point Formation (Quinn et al., in prep.) confirms this change in depositional environment.

The singular and most important conclusion reached here is that, given the regional TAI data (Williams et al., in press.) it appears that the faulting probably had little overall affect and that the depositional environment appears to be the main reason for the change in the AAI's of the

acritarchs within the Winterhouse Formation.

## CHAPTER 4: ACRITARCH BIOSTRATIGRAPHY

### 4.1: ACRITARCH ASSEMBLAGE ZONES

#### 4.1.1: PREVIOUS INVESTIGATIONS

Published reports on Middle-Upper Ordovician organic-walled microplankton of North America are few. As late as 1965, only four species of Ordovician acritarchs had been described from the entire North American continent, these were from the Trenton Formation (Caradoc) of Anticosti Island, Canada (Staplin et al., 1965). Since that time, additional Canadian studies have included those of Dean and Martin (1978), Martin (1978, 1980, 1983, 1992), Legault (1982), Wright and Meyers (1981), Jacobson and Achab (1985) Miller and Williams (1988). In the United States, studies have been made by Loeblich (1970a, b), Loeblich and Tappan (1969, 1971a, b, 1978), Loeblich and MacAdam (1971), Tappan and Loeblich (1971), Jacobson (1978a,b, 1979), Colbath (1979, 1980) and Miller (1991).

Only Martin (1978) has published work on Upper Ordovician acritarchs from the Winterhouse Formation. Her find of four acritarchs (*Multiplicisphaerium bifurcatum*, *Goniosphaerium polygonium*, *Peteinosphaeridium breviradiatum* and *Actipilion* aff. *A. druggii*) was not sufficient to permit a precise age assignment for the Winterhouse Formation as the species were long ranging. However, chitinozoa present in the formation did allow her to assign a Caradoc age to the upper part of the formation.

Outside North America, Middle to Upper Ordovician acritarchs have been studied in several regions. Work on Middle to Upper Ordovician acritarchs of the Baltic included some of the earliest studies in acritarch taxonomy that were undertaken by Eisenack (1954, 1962, 1965a, b, 1969, 1976). Additional studies on Ordovician acritarchs include those by Kjellström (1971a, b, 1972, 1976) on the baltisphaerids of Sweden. Studies in Finland include those of Tynni (1975), Bergman et al. (1982) and Uutela (1989). More recently, Uutela and Tynni (1991) has studied Ordovician acritarchs of Estonia. A Polish study of acritarchs in Ordovician strata was carried out by Gorka (1969). Additional European studies were from Belgium (Martin, 1966a, 1966b, 1968); Spain (Cramer, 1964) and Britain (Turner, 1984).

Outside Europe and North America, studies of Ordovician acritarchs, and in particular those from Upper Ordovician strata, are few. These include acritarchs of Australia (Playford and Martin, 1984); Morocco (Elaouad-Deddaj, 1978, 1988); Jordan (Keegan et al., 1990); Sahara Algerian (Jardine et al., 1974) and acritarchs and other palynomorphs of Libya (Molyneux, 1988; Molyneux et al., 1996; Molyneux and Paris, 1985).

#### 4.1.2: ACRITARCH ASSEMBLAGE ZONES

Forty-four samples from a composite section of the Winterhouse Formation were analysed for their acritarch content. A total of 74 well preserved palynomorphs were identified and assigned to 31 different genera (Chart 1 and 2). In examining the total assemblage from the Winterhouse Formation, four genera dominate (greater than 70%) the flora. These are:

*Leiosphaeridia*, *Micrhystridium*, *Polygonium* and *Gloeocapsomorpha*. The remaining 30%, each contributing to less than 5% of the total assemblage, are assigned to 27 different genera. When a comparison is made of the percent relative abundance for each of the four dominant genera of the Winterhouse Formation, the abundance of *Leiosphaeridia* and *Gloeocapsomorpha* remains relatively unchanged, whereas a significant change in dominance occurs between *Micrhystridium* and *Polygonium*. *Micrhystridium* shows its greatest abundance in the lower and middle parts of the Shore section, while *Polygonium* display its greatest abundance in the upper Winterhouse Formation of the Cliff and River sections. This switch in the dominant genera from a *Micrhystridium* rich assemblage in the lower part of the Winterhouse Formation to a *Polygonium* rich assemblage in the upper part of the formation is recognized in the assemblage zones outlined below.

Assemblage zones of the Winterhouse Formation have been differentiated statistically using CONISS (Grimm, 1987), a data analysis program of the TILIA software package (Grimm, 1991). The CONISS dendrogram program carries out stratigraphically constrained cluster analysis by the method of an incremental sum of squares, constrained in that the clusters contain only stratigraphically adjacent samples. The incremental sum of squares is one of the most widely used methods of cluster analysis for palynology. This program has been chosen for its ease in data analysis and presentation, while providing mathematically accepted criteria for defining zones. Nevertheless, this statistical zonation is not significantly different from more subjective (visual) criteria typically used for zonal identification. It does however

provide intriguing splits which may one day prove significant for deriving a very highly refined biostratigraphy.

From the CONISS dendrogram plot of Chart 2, a total sum of nine squares is used to differentiate three clusters of taxa which are, in turn, used to define three assemblage zones within the Winterhouse Formation. These assemblage zones are based on the stratigraphic value and relative abundance of all 74 species identified from the forty-four samples from the Winterhouse Formation. For ease in identification and further description of the assemblage zones only those species with relative abundances of more than 15% of the total assemblage are discussed, along with species that are believed by the author to be of some significance for zonation purposes (see Chart 1). These significant species either have their peak abundances or their first occurrence within the defined zones. The range and relative abundance for all species identified in the Winterhouse Formation, including those rare species that are not included in the zonations of Chart 1 are presented in Chart 2.

Lower, middle and upper Winterhouse assemblages have been defined based on the dendrogram plot in Chart 1 and 2. The lower and middle Winterhouse assemblages are named the *Veryhachium* Assemblage Zone (VA Zone) and the *Micrhystridium* Assemblage Zone (MA Zone). Both are confined to the Shore section in samples H-3-95 to H-44-95, and H-69-95 to H-90-95 respectively. The upper Winterhouse assemblage is called the *Polygonium* Assemblage Zone (PA Zone). It corresponds with the uppermost portion of the Winterhouse



Formation. The *Polygonium* Assemblage Zone is found in the Cliff section, samples H-48-95 to H-52-95 and the River section, samples H-54-95 to H-64-95.

The ***Veryhachium* Assemblage Zone** (VA Zone) samples (H-3-95 to H-44-95), is characterized by the association and peak abundances of the following species: *Gloeocapsomorpha* sp., *Veryhachium trispinosum*, *Villosacapsula setosapellicula*, and *Micrhystridium fragile*. Other species which show significant abundances in this zone include: *Micrhystridium shinetonense*, *Multiplicisphaeridium* sp B., *Ammonidium parvipinnatum*, *Comasphaeridium* sp. A and *Baltisphaeridium filosum*. Other species that occur in relatively low abundances include: *Micrhystridium* sp. C, *Micrhystridium equispinosum*, *Polygonium gracile*, *Veryhachium oklahomense*, *Lophosphaeridium aequicuspatum*, *Veryhachium valiente*, *Villosacapsula entrichos*, *Multiplicisphaeridium* sp., and *Polygonium connectum*. In this zone, although they occur together, the abundances of *Veryhachium trispinosum* and *Villosacapsula setosapellicula* show inverse relationships to each other.

The ***Micrhystridium* Assemblage Zone** (MA Zone) samples (H-69-95 to H-90-95), is characterized by an increase in the relative abundance and peak abundance of *Micrhystridium* sp. C, *Micrhystridium equispinosum*, *Veryhachium oklahomense*, *Multiplicisphaeridium* sp. B, *Micrhystridium aremoricum*, *Comasphaeridium varispinosum*, *Multiplicisphaeridium martae*, and *Polygonium* sp. C. *Comasphaeridium* sp. A and *Baltisphaeridium filosum* are still present in significant amounts, along with *Polygonium gracile*. In this zone there is a

significant decrease in *Micrhystridium fragile* from the underlying VA Zone. So too, *Villosacapsula setosapellicula* decreases from 18% at its maxima in the VA Zone to 0%, *Veryhachium trispinosum* decreases from 35% at its maxima in the VA Zone to 2%, and *Ammonidium parvipinnatum* decreases from 12% at its maxima in the VA Zone to 1%. *Baltisphaeridium dispar*, sporadically present in the VA Zone, appears to be more consistently present in the MA Zone.

The **Polygonium Assemblage Zone** (PA Zone) samples (H-48-95 to H-52-95 and H-54-95 to H-64-95), is characterized by an increase in the relative abundance and peak abundance of *Polygonium gracile*, *Veryhachium valiente*, *Lophosphaeridium aequicuspidatum*, *Villosacapsula entrichos*, *Moyeria cabottii*, *Lophosphaeridium endense*, *Lophosphaeridium papillatum*, *Polygonium* sp. C, and the first appearance of *Cryptospore* sp. A and B. The trend of declining abundances of *Villosacapsula setosapellicula*, *Veryhachium trispinosum* and *Ammonidium parvipinnatum* continues from the VA Zone. *Micrhystridium* are replaced with *Polygonium* as the dominant genus. *Baltisphaeridium dispar* is apparently absent in this zone.

#### 4.1.3: COMPARISON WITH OTHER ACRITARCH ZONATIONS

Several publications (from Baltoscandinavia, Europe, North America and North Africa) have discussed acritarchs from rocks of Caradoc-Ashgill series, but few give precise stratigraphic information on assemblages from continuous sections with good independent age control.

Most of the studies on Upper Ordovician acritarchs concentrate on taxonomy; only three authors have erected local or regional biostratigraphic zonations. These include work from the Algerian Sahara (Jardiné et al., 1974); Northeast Libya (Hill and Molyneux, 1988); and from Jordan (Keegan et al., 1990). Only two species (*A. crassus* and *V. setosapellicula*) from the formal biozones of Jardiné et al. (1974) and Keegan et al. (1990) occur in the Winterhouse Formation. Both of these species range in age from the Caradoc to Ashgill series. The Ordovician biozones (Ca1 (Caradoc) and As1, As2 (Ashgill)) of Northeast Libya, (Hill and Molyneux, 1988), have 12 species in common with those found in the Winterhouse Formation. These include four species (*V. irroratum*, *A. cf. crassus*, *V. lairdii-valiente* and *V. trispinosum*) from biozones Ca1, As1 and As2; and eight species (*M. irregulare*, *O. heteromorphicum*, *V. reductum*, *L. fusiformis*, *V. lairdii*, *V. oklahomense*, *V. setosapellicula*, *C. diaphorosa*) from biozones As1 and As2. All species range in age from Caradoc to Ashgill. Text-Figure 4.1, indicates the biostratigraphic correlation of the Winterhouse Formation with selected Upper Ordovician acritarch biozones from Northern Gondwana (Molyneux et al., 1996).

#### 4.1.4: AGE AND CORRELATION

The Winterhouse Formation contains biostratigraphically useful graptolites which assist in establishing a Caradoc age for this unit. Quinn et al., (in prep.) confirmed an earlier report of *Climacograptus spiniferus* by O'Brien (1973) in the upper Winterhouse Cliff section, and also recorded *Geniculograptus pygmaeus*, *Orthograptus calcaratus*(?) and *Amplexograptus*

SYSTEM	SERIES		NORTH AMERICAN		NORTHERN GONDWANA			LAURENTIA
			STAGES	GRAPTOLITE ZONES	Algerian Sahara Jardine et al. (1974)	Northeast Libya Hill & Molyneux (1988)	Jordan Keegan et al. (1990)	Winterhouse Fm. this study
UPPER ORDOVICIAN	CINCINNATIAN	ASHGILL	Gamachian	peraculpius extraordinarius pacificus	F	As2	A	
			Richmondian	prominens complanatus				
			Maysvillian	manitoulinensis		— 2 —	B	
			Edenian	pygmaeus		As1		
	MOHAWKIAN	CARADOC	Shermanian	spiniferus			JO2	PA ZONE — ? —
			Kirkfiedian	ruodemanni				MA ZONE
			Rocklandian	americanus				— ? —
			Blackriveran	bicornis		Cal		VA ZONE ?
				gracilis				

Text-Figure 4.1: Correlation chart of Upper Ordovician acritarch biozones of Northern Gondwana and the Winterhouse Formation (after Molyneux et al., 1996).

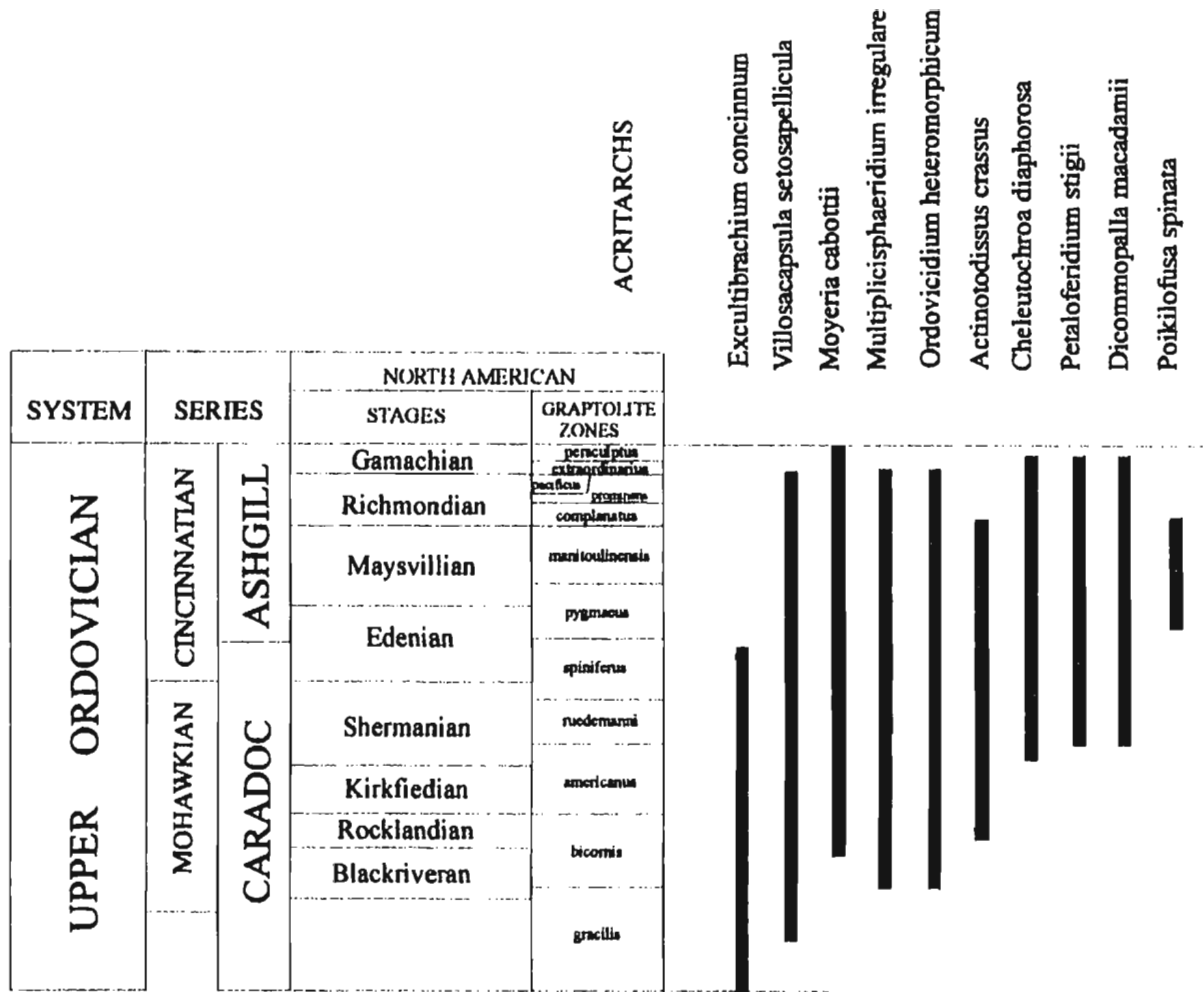
sp. The association of *C. spiniferus* and *G. pygmaeus* demonstrate that the upper Winterhouse Formation at the Cliff section is situated in the lower part of the *G. pygmaeus* Zone (i.e., early Cincinnati, late Caradoc) of eastern North America, where these two graptolite species occur together. Two horizons in the uppermost part of the upper Winterhouse River section, (Quinn et al. (in prep.), Waterfall section) yielded abundant *C. typicalis*. This graptolite is known to occur in both the *C. spiniferus* and *C. pygmaeus* zones, suggesting an early Cincinnati age for this upper portion of the Winterhouse Formation.

Graptolites from the lower part of the Winterhouse Formation in the Shore section (Quinn et al., in prep.) give no definitive age assignment for the lower portion of the Winterhouse Formation, or they appear to belong to a new species of *Amplexograptus*. However, Stait and Barnes (1991), in their review of work carried out on the macrofauna from the underlying Lourdes Formation (in particular trilobite work carried out by Dean, 1979) concluded that the middle and upper Lourdes Formation was early-middle Mohawkian in age. Some authors (Stait and Barnes, 1991; Quinn et al., in prep.) have argued that the boundary between the Lourdes and Winterhouse Formations is gradational. From this reason, it may be concluded that the lowermost Winterhouse is middle Caradoc in age. In this study, the boundary between the Lourdes and the Winterhouse Formations is not obviously gradational and one can not eliminate the possibility that an unconformity exists. That being the case, the base of the Winterhouse Formation may be as young as Shermanian (late Caradoc).

Based on graptolite evidence of Quinn et al. (in prep.) and the age determination based on the underlying Lourdes Formation in Stait and Barnes (1991), it is evident that the Winterhouse Formation is almost entirely Caradoc in age, with possibly a thin interval near the top of the formation being Ashgill. It must then be assumed that most acritarchs found within the Winterhouse Formation are Caradoc in age. Observation of the stratigraphic range (Text-Figure 4.2) of selected acritarchs species (*V. setosapellicula*, *M. cabottii*, *M. irregulare*, *O. heteromorphicum*, *P. stiggii*, *C. diaphorosa*, *D. macadamii*, *A. crassus*, *P. spinata* and *E. concinnum*) published by Molyneux et al. (1996), and which occur in the Winterhouse Formation, appears to confirm this Caradoc age assignment. Further investigation of other microflora, in particular the abundant chitinozoans, may help to provide additional evidence for a precise age assignment.

In comparing the assemblage of acritarchs found in the Winterhouse Formation with those acritarchs found in other localities, some similarities exist. It should be noted here that of the 74 palynomorph morphotypes described in this study, 25 taxa have only been identified to the generic level. Either these are new species or appropriate literature that may have described these species has not been reviewed.

In reviews from elsewhere in North America, the Winterhouse Formation only has 9 of its 74 species in common with the Eden Shale (Caradoc) of Indiana (Colbath, 1979); 6 species in common with the Trenton and Utica shales (Caradoc) of the Saint Laurent Platform,

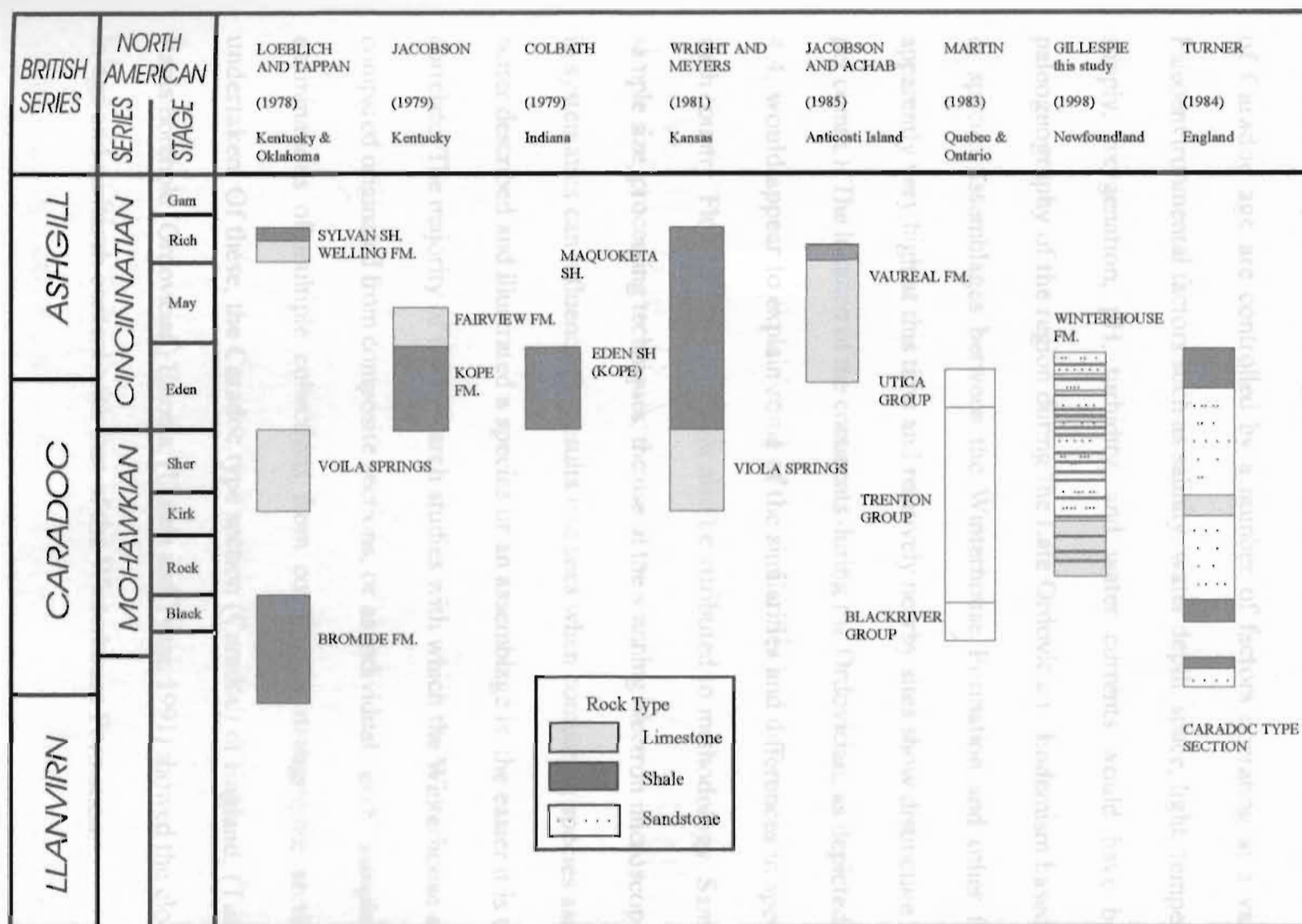


Text-Figure 4.2: Ranges of selected Upper Ordovician acritarchs (after Molyneux et al., 1996).

Quebec and Ontario (Martin, 1983); and 4 species in common with the White Head Formation (Caradoc-Ashgill), Quebec (Martin, 1980). The Winterhouse Formation has 10 species in common with the Vaureal Formation (Ashgill) of Anticosti Island (Jacobson and Achab, 1985); 3 species in common with the Clay Ferry (Edenian) of Kentucky (Jacobson, 1978a); 15 species in common with the (Middle to Upper Ordovician) New York State and Cincinnati composite sections from Clay Ferry and Maysville (Jacobson, 1978b); and 8 species in common with the Maquoketa shale and former Viola Limestone (now Viola Springs Limestone, Amsden et al., 1988), Late to Middle Ordovician of Kansas (Wright and Meyers, 1981). With a single dredge sample, dated as Caradoc-Ashgill from Orphan Knoll (Legault, 1982), the Winterhouse Formation has 14 species in common. Text-Figure 4.3 indicates the stratigraphic correlation of the Winterhouse Formation with selected North American sections.

Outside North America, the Winterhouse Formation shares 7 species in common with Caradoc-Ashgill samples of Morocco, (Elaouad-Debbaj, 1988); 12 species from well cuttings (Caradoc-Ashgill) of Northeast Libya, (Hill and Molyneux, 1988); and 7 species in common with Middle Ordovician baltisphaerids of Gotland, Sweden, (Kjellström, 1971a). The Winterhouse acritarchs show their best correlation, a total of 19 species in common with the Caradoc type section of England, (Turner, 1984) and 31 species in common with the Repla borehole (Ordovician) in Estonia, (Uutela and Tynni, 1991). These appear, to date, to be the most complete acritarch studies available for the Upper Ordovician.





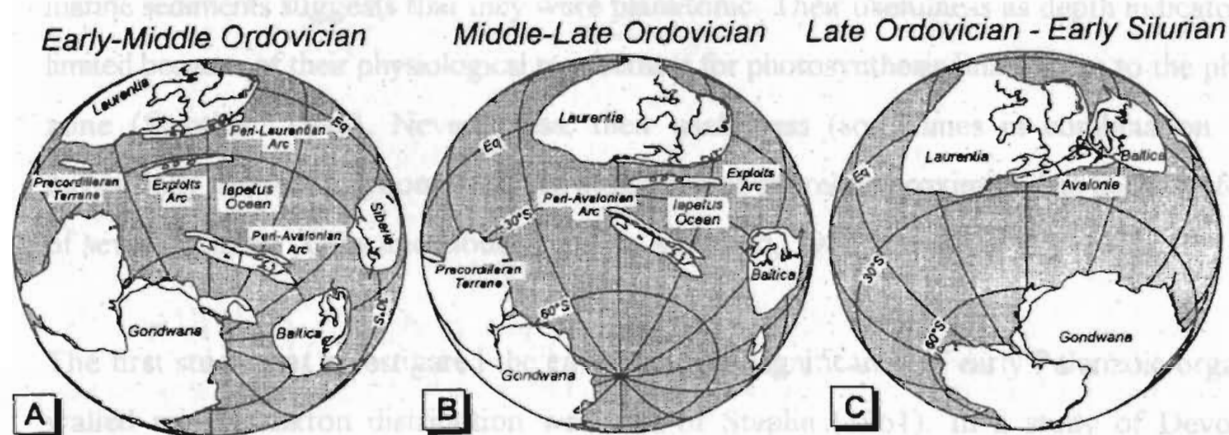
Text-Figure 4.3. Age correlation of several North American sections including the Caradoc type section from England (after Wright and Meyers, 1981). Revised formation nomenclature for Oklahoma and Kansas from Amsden et al., 1988.

Differences in species assemblages between the Winterhouse Formation and other formations of Caradoc age are controlled by a number of factors operating at a variety of scales. Paleoenvironmental factors such as salinity, water depth, space, light, temperature, nutrient supply, oxygenation, pH, turbidity, and water currents would have been related to paleogeography of the region during the Late Ordovician. Endemism based on differences in species assemblages between the Winterhouse Formation and other formations was apparently very high at this time and relatively nearby sites show distinctive floras, (Burden *per comm.*). The location of the continents during the Ordovician, as depicted in Text-Figure 4.4, would appear to explain some of the similarities and differences in species listed from each country. Floral differences might also be attributed to methodology. Sampling intervals, sample size, processing techniques, the use of the scanning electron microscope and advances in systematics can influence the results one sees when comparing species assemblages. The better described and illustrated a species or an assemblage is, the easier it is to compare and correlate. The majority of the acritarch studies with which the Winterhouse assemblage was compared originated from composite sections, or as individual “grab” samples. Few detailed examinations of multiple collections from continuous stratigraphic sections have been undertaken. Of these, the Caradoc type section (Caradoc) of England, (Turner, 1984) and Rapla borehole (Ordovician) Estonia, (Uutela and Tynni, 1991) showed the closest similarities in age and acritarch content with that of the Winterhouse Formation.

#### 4.1.5: ACRITARCH PROVINCIALISM

In contrast to the relatively large number of publications on Early Ordovician acritarch provincialism, only Vavrdová (1974) has discussed acritarch provincialism for the Late Ordovician. In her discussion of the geographical differentiation of Ordovician acritarch assemblages Vavrdová, recognized two main provinces in Europe: 1) a Baltic province, characterised by the prevalence of acanthomorphids, and 2) a Mediterranean province, characterised by the occurrence of diacromorphids. For the Late Ordovician, Vavrdová's Baltic province is dominated by *Baltisphaeridium longispinosum* (Eisenack), *B. multipilosum* (Eisenack), *B. digitatum* (Eisenack), *B. varsoviensis* Górka, *B. plicatispinae* Górka, *Peteinosphaeridium trifurcatum* (Eisenack) Staplin et al., *Goniosphaeridium polygonium* (Eisenack), *Orthosphaeridium octospinosum* Eisenack, *O. rectangulare* (Eisenack), *Pulvinosphaeridium pulvinellum* Eisenack and *Hystriosphaeiridium wimani* Eisenack. Her Mediterranean province is dominated by *Baltisphaeridium eisenackium* (Deunff) Downie, *Baltisphaera ternata* Burmann, *B. quadrinata* Burmann, *B. transitoria* Burmann, *Veryhachium trispinosum* (Deunff), *V. rosendae* Cramer, *V. elenea* Cramer, *Multiplicisphaeridium ramusculosum* (Deflandre) Staplin et al., *M. arbusculiferum* (Downie) Loeblich, and *Diexallophasis granulatispinosum* (Downie) Loeblich. Jacobson (1979, p. 1210) noted that many of Vavrdová's Baltic provincial indicators are found in North America whereas her Mediterranean forms are rare or absent. It is only in Vavrdová's Baltic assemblage that there are any resemblances (at the generic level) to species found in the Winterhouse Formation. The Mediterranean species are absent, except for the widely

dispersed and cosmopolitan *Veryhachium trispinosum* (Deunff).



Text-Figure 4.4: Selected views of Early, Middle, and Late Ordovician paleogeography (from Noicaill et al., 1997).

## **4.2: ACRITARCH PALEOECOLOGY**

### **4.2.1: REVIEW OF SELECTED STUDIES**

There have been relatively few detailed studies on the paleoecology of acritarchs (Staplin, 1961; Wall, 1965; Smith and Saunders, 1970; Jacobson, 1979; Colbath, 1980; Dorning, 1981; Al-Ameri, 1982). However, certain elements of their ecology are well known. Acritarchs are thought to be exclusively marine (Strother, 1996) and their occurrence in most types of marine sediments suggests that they were planktonic. Their usefulness as depth indicators is limited because of their physiological requirement for photosynthesis limits them to the photic zone (Strother, 1996). Nevertheless, their usefulness (sometimes in combination with terrestrially derived palynomorphs) as indicators of shoreline proximity, has been the focus of several studies (Gray and Boucot, 1972; Al-Ameri, 1982; Gensel et al., 1990).

The first study that investigated the environmental significance of early Paleozoic organic-walled microplankton distribution was that of Staplin (1961). In a study of Devonian hystrichosphaerids of the Duvernay reef in Alberta, Staplin demonstrated that the different distribution patterns of hystrichosphaerids are apparently influenced by proximity to reefs. He observed that simple spherical forms were common in shales (off reef) interbedded with reef carbonates but that their diversity increased distally away from the reefs. Thin-spined forms (gracile acanthomorphs) occur only rarely within 1 mile of a paleo-reef, while polyhedral, thick spined and saccate forms are found only to occur more than 4 miles from the reef complex. Staplin (1961) also noted that quiet, deeper waters in off-reef areas had the highest diversities.

Wall (1965) studied organic-walled microfossils including acritarchs from the Lower Jurassic of Britain and found two types of microplankton assemblages, one showing a tendency toward uniformity of composition with a strong dominance by a single species, the other being more varied in composition. He concluded that assemblages dominated by a single

species were derived from algae inhabiting inshore waters, whereas species-rich, heterogeneous assemblages accumulated in quiet offshore environments. This distribution is analogous to that in modern environments for microplankton. Wall (1975) also stated that members of simple Acanthomorpha (*Micrhystridium* ssp. and *Baltisphaeridium* ssp.) appear to have favoured an inshore, partly enclosed environment, whereas members of the Polygonomorpha (*Veryhachium* sp.) and Netromorpha (*Leiofusa* sp., *Domasia* sp. and *Cantulodinium* sp.), along with Acanthomorph species, appear to have favoured the open sea environment. The character of Wall's assemblages also showed a consistent relationship with cycles of sedimentation and sea-level change. In the early stages of a transgression, the assemblages consisted wholly of acanthomorphids. Establishment of open-marine conditions, determined from the deposition of marls and silty shale facies, resulted in the existence of a more diverse flora. Marine regression and deposition of coarser clastics resulted in a reduction in the diversity and increasing abundance of microplankton; acanthomorphs again become the dominant species.

Smith and Saunders (1970) in a study of Silurian rocks of Pennsylvania, suggested that acritarchs reflect marine rather than fluvial conditions and that their preservation was better in deep water, open marine sediments. They also found acritarchs that were correlated with the energy of the depositional environment and in part controlled by the direction of prevailing currents.

Jacobson (1979) reinforced Staplin's model in his study of acritarchs from Middle and Upper Ordovician limestones and shales from Kentucky, Ohio and New York. Jacobson established three abundance classes of acritarch species, reflecting three marine paleoenvironments. He found that *Leiosphaeridia* dominated assemblages correspond to a near shore shallow-water environment, petinosphaerid-*Dicommopalla* assemblages correspond to a shoal environment, and baltisphaerid-veryhachid-*Polygonium*-*Micrhystridium* assemblages correspond to an

open-marine environment. Such findings enabled him to recognize transgressions by relating the introduction of an offshore assemblage into his shallow-water and shoal assemblages. He also found a correlation in the distribution of acritarchs, conodonts and chitinozoa which might enable use of these flora interchangeably when interpreting the three paleoenvironments.

Colbath (1980) attributed inverse abundance fluctuations in Upper Ordovician organic-walled microplankton from Indiana to changes in water masses. He concluded that two assemblages or communities of acritarchs are not controlled by facies variation but rather are considered characteristic of different water masses. However, Colbath could not exclude an alternate model of Laufeld (1974), which suggested that random sampling of seasonal fluctuations within a single phytoplankton assemblage might account for the inverse relationship between communities.

Dorning (1981) in a study of Silurian acritarch distribution in the Ludlovian shelf sea of South Wales and the Welsh Borderland, identified three distinct assemblages representing nearshore, offshore shelf and deep water environments. Doring's nearshore assemblage had low diversity with low to moderate abundances for 5-15 species per sample. In this assemblage leiospheres were dominant while *Veryhachium* (with three processes) and *Micrhystridium* were common. Other genera were rare. The offshore shelf assemblage had high diversity with moderate abundances for 10-90 species per sample. In this assemblage no one taxon dominated although 4-8 genera (each of 5-20%) would comprise up to 70-90% of the total. The deep water assemblage had low diversity with low to moderate abundance for 2-15 species per sample. Taxa dominated by leiospheres were similar to the near shore assemblage, with the addition of *Cymatiosphaera*, *Lophosphaeridium* and *Pterospermella*.



Dorning (1981) also noticed trends in species diversity and postulated intraspecific morphological differences between onshore and offshore taxa. Some forms appeared to be more common inshore, others offshore. For instance specimens of *Micrhystridium* found offshore had longer processes than their inshore counterparts. *Multiplicisphaeridium* showed greatest diversity offshore, while *Verhachium* commonly had 3–4 processes inshore and up to 6 processes farther offshore where they merged with forms transitional to *Micrhystridium* ssp. Dorning (1981) also suggested that acritarch assemblages showing a strong dominance of a single taxon might represent blooms. According to Strother (1996), Dorning's quantitative model was limited, largely because of the similarity of his offshore and near shore assemblages.

Al-Ameri (1982) used an assemblage of microfossils (spores, acritarchs, chitinozoans, tasmanitids, scolecodonts, plant tissue, eurypterid cuticle, and graptolite siculae) and sedimentological features to determine Palaeozoic palaeoenvironments in Libya.

Five types of palynofacies were identified and applied to models relating their distance from shore. Palynofacies type 1 is a terrestrial facies of spores and megaflores that was deposited in a fluvial, lacustrine or post-glacial environment. Palynofacies type 2, constituted abundant miospores, sphaeromorphs and tracheid-like fragments. This assemblage of microfossils was deposited in poorly sorted and coarsely bedded sandstones within an intertidal marine environment. Palynofacies type 3, is abundant in miospores and sphaeromorphs, including a rare diversification of acanthomorphs, netromorphs and polygonomorphs along with chitinozoa, cuticles and tracheid-like fragments. This assemblage of microfossils was deposited in sandstones, siltstones and shales typical of an inner neritic environment. Palynofacies type 4, is characterized by a decrease in the diversity of the miospores and sphaeromorphs. The acanthomorphs become highly diversified; in addition the assemblage of polygonomorphs, netromorphs and chitinozoa appear to peak in their diversity. This

assemblage of microfossils was deposited in laminated silts and shales associated with an outer neritic environment. Palynofacies type 5, is an abundant assemblage of sphaeromorphs and polygonomorphs. Miospores are rare or absent in this facies and there is a significant decrease (relative to palynofacies type 4) in the diversity of polygonomorphs, netromorphous and chitinozoa. This assemblage of microfossils was deposited in laminated shales associated with an outer neritic zone or open marine environment.

This study complimented previous studies on shelf sediments (Staplin, 1961; Smith and Saunders, 1970; Wall, 1965; Jacobson, 1979) in that the quantity of terrestrially derived spores and pollen decreases with increasing distance from the shoreline, whereas quantity and diversity of acritarchs increases with increasing distance from the shore.

Gensel et al. (1990) suggested that mixed assemblages which contain known terrestrial elements such as spores, cryptospores, nematoclasts and plant fragments can be used to infer proximity to shoreline and thus reduce the uncertainty associated with assemblages dominated by simple sphaeromorphs. Gray and Boucot (1972) used the presence of cryptospores to indicate near shore deposition across the Ordovician/Silurian boundary in Ohio.

From the above cited studies it is evident that the distance from shore, distribution within contemporaneous water masses, transgressive-regressive cycles and overall phytoplankton productivity have all been considered to influence the occurrence of acritarchs. Keeping this in mind, and considering the depositional environment of the Winterhouse Formation as interpreted by Quinn et al. (in prep.) the following section discusses the paleoenvironmental interpretation of the three assemblage zones identified within the Winterhouse Formation.

#### 4.2.2: PALEOENVIRONMENTAL INTERPRETATION

The Long Point Group is interpreted (Quinn et al., in prep.) as a shelf succession with the Lourdes Formation limestones representing a deepening succession into the overlying Winterhouse Formation, an offshore, storm dominated shelf. The Winterhouse Formation has both siliciclastic material, supplied from tectonic highlands to the east (Quinn et al., in prep.), and carbonates possibly related to exposure of the peripheral bulge to the west of the evolving foreland basin (Stockmal et al., 1995). The siliciclastics of the Misty Point Formation, which gradationally overlie the Winterhouse Formation, have been interpreted to represent progradation of marginal marine or deltaic deposits (Quinn et al., in prep.).

For this study, samples from the Winterhouse Formation were collected at regular intervals from silty and shaly strata. Statistical analysis of the acritarchs extracted from these samples revealed three assemblage zones. These assemblage zones are interpreted to be related (in a broad sense) to three stages in the development of a shelf succession in a evolving basin. The lowermost assemblage zone, herein referred to as the **VA Zone**, is correlated with deepening and drowning of a carbonate shelf sequence. This is consistent with the presence of limestone conglomerates which are indicative of slumping onto the shelf (Bergström et al., 1974) from the nearby Lourdes Formation as a result of shelf instability or brief periods of low stands. The **MA Zone** occurs stratigraphically above the VA Zone and is interpreted to be correlative with an offshore shelf sequence showing a greater degree of mixing between the carbonate and the siliciclastic material. This zone has only one limestone conglomerate and is considered to be a transition between the underlying VA Zone and the overlying PA Zone. It indicates a period of relative stability on the shelf. The uppermost **PA Zone** is correlative with an offshore clastic shelf sequence. It contains no limestones and includes a thick black shale sequence indicative of a restricted basin environment. The strata in this zone are locally overturned and structurally disrupted, related to their proximity to the sole of the Round Head Thrust (Williams et al., 1995; Quinn et al., in prep.). These three assemblage zones and their environmental interpretation are discussed in more detail below. A complete list of species

present in each of the three zones is given in Chart 2.

The **VA Zone**, which spans approximately 175 metres of strata, is characterized by the association and peak abundances of the following species: *Gloeocapsomorpha* sp., *Veryhachium trispinosum*, *Villosacapsula setosapellicula*, and *Micrhystridium fragile*. This zone is seen in the lower half of the Shore section of the Winterhouse Formation where the limestones of the Lourdes Formation appear to pass gradationally into calcareous shales and siltstones of the Winterhouse Formation. Stait and Barnes (1991) suggested that water depth gradually increased beyond that at which primary carbonate production could take place. Quinn et al. (in prep.) suggested that an increase in the clastic supply may have also been a contributing factor. In this zone, the succession of rocks is visibly dominated by detrital carbonates, including three major limestone conglomerate horizons (Quinn et al., in prep.: limestone facies). The underlying Lourdes Formation is considered to be the source for the limestone conglomerates (Bergström et al., 1974). This may indicate that a carbonate bank was relatively near by and the assemblage of acritarchs found in this zone probably thrived where primary carbonate production was relatively high. The species of this zone are deposited or live in a storm dominated carbonate shelf environment and quickly rebounded in numbers and diversity (Chart 2, Text-Figure 1.2 ) after major shelf disturbances.

With closer detailed examination of additional samples, combined with constrained cluster analysis (as used in this study) and plots of the relative abundances of a variety of marine fauna/flora groups, it may be possible to relate these changes in flora to transgressive-regressive phases, coastal onlap curves, and distance from shoreline (Stover et al. 1996, p. 709). Work by Haq et al. (1987) identified a relationship of biohorizons and zones to depositional sequences. Their sequences consisted of constrained strata and three-dimensional facies packages that reflected changing environments associated within overall transgressive-regressive cycles. Several driving mechanisms were proposed for these changes in sea level

including tectonic changes and Milankovitch cycles.

At the present sampling interval of 5 metres one only observes hints of systematic changes in assemblages within each of the three zones. Hence, only general comments with regard to transgressive-regressive phases can be made.

It is significant that a clear inverse correlation in abundances between *Veryhachium trispinosum* and *Villosacapsula setosapellicula* (Chart 1) occurs. This appears to be correlative with a facies change. Colbath (1980) suggested that such inverse correlations may also be characteristic of different water masses. *Villosacapsula setosapellicula* appears to be highest in carbonate rich samples which occur at the base of the Winterhouse in the transition between the Lourdes limestone and the Winterhouse shales. This species does not occur in the overlying MA Zone where the environment shows a greater degree of mixing between carbonate and siliciclastic facies, with the siliciclastics being the more dominant. The abrupt disappearance of *Villosacapsula setosapellicula* at the top of the VA Zone is not considered a true last appearance, since it is known to occur in the upper Ashgill, (Molyneux et al., 1996). Its absence in the MA Zone suggests that it is restricted to a shallow water, carbonate rich shelf. Laufeld (1974) suggested that random sampling of seasonal fluctuations within a single phytoplankton assemblage accounted for some inverse relationships between communities. This is not considered to be the case here because the sampling interval of 5 metres is considered to be too large to reveal seasonal fluctuations in abundances.

The **MA Zone**, which overlies the VA Zone, is characterized by an increase in relative abundance and peak abundances of *Micrhystridium* sp. C, *Micrhystridium equispinosum*, *Veryhachium oklahomense*, *Multiplicisphaeridium* sp. B, *Micrhystridium aremoricum*, *Comasphaeridium varispinosum*, *Multiplicisphaeridium martaе*, and *Polygonium* sp. C (see sect. 4.5.2 of this chapter). This zone comprises approximately 175 metres of strata in

outcrop. Another 400-500 metres of unexposed strata overlies this zone and could belong to either the MA Zone or the overlying PA Zone. The assemblage in the MA Zone is consistent with similar assemblages (Staplin, 1961; Wall, 1965; Dorning, 1981; Al-Ameri, 1982) found in offshore shelf- marginal marine environments and is consistent with a model which considers the middle of the Winterhouse Formation to represent deeper water at the edge of the shelf. The disappearance of *Villosacapsula setosapellicula* within this zone supports the idea that these shelf deposits were formed in an environment which is either too deep for it to survive or resulted from changes in nutrients and water quality as indicated from an increased supply of clastic detritus. This zone is considered here to be a transitional zone between the carbonate rich VA Zone and the overlying siliciclastic rich PA Zone.

The **PA Zone**, the highest zone in the succession, is characterized by an increase in the relative abundance and peak abundances of *Polygonium gracile*, *Veryhachium valiente*, *Lophosphaeridium aequicuspidatum*, *Villosacapsula entrichos*, *Moyeria cabottii*, *Lophosphaeridium endense*, *Lophosphaeridium papillatum*, *Polygonium* sp. A, and the first appearance of Cryptospore sp. B (see sect. 4.5.2 of this chapter). This zone includes approximately 110 metres of strata in an outcrop that has undergone an undetermined amount of tectonic thinning. It includes strata exposed at the River and Cliff sections where the siliciclastic (silty shale) facies prevail; there are no limestones. In this particular zone, the sediments coarsen upward, possibly representing shallowing of the shelf. The influence of a changing environment, indicated by the transition of the Winterhouse Formation into the overlying and possibly deltaic sediments of the Misty Point Formation, is supported by the first occurrence of cryptospores in the palynology assemblage with putative terrestrial spores. This shallowing of the shelf could account for the decrease in the relative abundances of species found in the MA Zone, and in particular the *Micrhystridium* species. It might also account for the observed increase in diversity of the acritarch assemblage and the addition of possible terrestrial material. It must be emphasised that strata belonging to this zone, and in

particular the Cliff section with its thick black shales, are locally overturned and structurally disrupted. With such unclear structural relationships, it may be that these sediments have been thrust from another part of the basin.

#### 4.2.3: SIGNIFICANCE OF THE DOMINANT GENERA

In the overall assemblage of acritarchs in the Winterhouse Formation, four genera dominate (greater than 70%) the flora, namely *Leiosphaeridia*, *Micrhystridium*, *Gloeocapsomorpha*, and *Polygonium*. The remaining 30% is divided among some 27 different genera all with less than 5% of the total assemblage. The Winterhouse Formation has a rich and diverse assemblage of palynomorphs. This combination of species (see sect. 4.5.2 of this chapter) and diversity is in keeping with the interpretation of Quinn et al. (in prep.) which shows the Winterhouse Formation as an offshore shelf deposit. It is also consistent with previous paleoenvironmental studies carried out by Staplin (1961), Wall (1965), Dornig (1981), Al-Ameri (1982) and Jacobson (1979) which show acritarch distribution in shelf and reef environments. The differences in the acritarch assemblages reflect changes on the shelf as manifested by differences in the sediment source. Thus 1) species living in an offshore carbonate rich siliciclastic poor environment are common in the VA Zone; 2) species living in an offshore mixed siliciclastic-carbonate shelf environment occur in the MA Zone and; 3) species living on a shallow shelf in a siliciclastic rich environment form the PA Zone.

The overall geologic significance of *Leiosphaeridia*, *Micrhystridium*, and *Polygonium* in the Winterhouse Formation can only broadly be defined because so many species exist. *Gloeocapsomorpha* sp. on the other hand, has a much tighter environmental control and the genus is dominated by one species, that is, *Gloeocapsomorpha prisca*. With its distinctive geochemical signature *Gloeocapsomorpha prisca* is a distinct biomarker for Ordovician oils. It is considered by Wicander et al. (1996) to be the main kerogen constituent (Ordovician algae) that generated Ordovician oils of North America (Williston, Michigan, Illinois, and Anadarko Basins), Australia (Canning and Amadeus Basins) and the Baltic basins. It has been

identified by Jacobson et al., 1995 as the main driving force behind the late Middle Ordovician organic carbon isotope excursion in the North American mid-continent.

Three habitats have been suggested for *Gloeocapsomorpha prisca* occurrence in the Williston Basin in Saskatchewan (Stasiuk et al., 1993): a lower salinity, upper water mass; a high salinity deeper water mass; and a stromatolitic mat in the deeper water realm. Another habitat proposed by Foster et al. (1990), for Baltic strata and using the analogy between extinct *G. prisca* and extant *Entophysalis major*, suggests that Estonian *G. prisca* lived during marine transgression in a relatively high salinity, intertidal, algal mats where they were transported seaward by water or wind, and into anoxic environments during marine regression. Jacobson et al. (1995) using the quasi estuarine model of Witzke (1990), proposed that *G. prisca* flourished in less saline, upper water layer.

Within the Winterhouse Formation, *Gloeocapsomorpha* sp. shows its peak abundance at the basal contact with the Lourdes Formation. Here in the transitional zone between the Lourdes and the Winterhouse Formations, the calcareous silty sediments may be interpreted as lag deposits from the underlying Lourdes Formation during a period of marine transgression. Only detailed isotopic work on *Gloeocapsomorpha* sp. of the Winterhouse Formation will verify its chemical composition and confirm the presence of *G. prisca*. Such an investigation will in turn shed more light on the depositional environment of the acritarch species that are associated with it and the petroleum potential of this formation.



## CHAPTER 5: CONCLUSIONS

Systematic analysis of a detailed list of seventy-four species has allowed assignment of a late Caradoc (late Mowhawkian-early Cincinnati) age to the Winterhouse Formation on the Port au Port Peninsula, western Newfoundland. Based on the age and similarity of acritarch assemblages, Winterhouse strata are correlative with the Fairview Fm., Eden shale, Maquoketa shale, lower Vaureal Fm. and, possibly, the Utica and upper Trenton Groups, of North America. Outside North America correlation of the Winterhouse Formation with other formations is more difficult; nevertheless it is most similar to the Caradoc type section of Britain.

A thermal maturation study of the palynomorphs from the Winterhouse Formation has indicated that the formation has sustained increasing alteration from bottom to top. This is the reverse of what would normally be expected and may be due to its proximity to the Round Head Thrust or more likely as a result of an oxidizing environment. An average Acritarch Alteration Index  $1.6 \pm 0.3$  in transmitted light for the Winterhouse Formation is not sufficient to have thermally matured the sediments, thus the section remains at or just above the oil window. The presence of *Gloeocapsomorpha* ssp. in the Winterhouse Formation may be an indicator that source beds exist in the surrounding area. *Gloeocapsomorpha prisca* is known to be the main driving force behind the late Middle Ordovician organic carbon isotope excursion in the North American mid-continent, and the main kerogen constituent in source

rocks capable of generating oil.

Applied cluster analysis has assisted in distinguishing three distinct assemblage zones in the Winterhouse Formation. These three zones should allow for significant stratigraphic control in future subsurface work as well as correlation between holes. The base or the first 150 metres of the Winterhouse Formation can be readily identified by using (*Gloeocapsomorpha* sp., *Veryhachium trispinosum*, *Villosacapsula setosapellicula*, and *Micrhystridium fragile*) an assemblage of species that defines the *Veryhachium* Assemblage Zone. The middle 150 metres ( $\pm$  500 metres of covered section) can be identified by using (*Micrhystridium* sp. C, *Micrhystridium equispinosum*, *Veryhachium oklahomense*, *Multiplicisphaeridium* sp. B, *Micrhystridium aremoricum*, *Comasphaeridium varispinosum*, *Multiplicisphaeridium martae*, and *Polygonium* sp. C) an assemblage of species that defines the *Micrhystridium* Assemblage Zone, while the upper 90-110 metres of the formation can be identified by using (*Polygonium gracile*, *Veryhachium valiente*, *Lophosphaeridium aequicuspidatum*, *Villosacapsula entrichos*, *Moyeria cabottii*, *Lophosphaeridium endense*, *Lophosphaeridium papillatum*, and *Polygonium* sp. C) an assemblage of species that defines the *Polygonium* Assemblage Zone. More detailed zonations may be possible with more closely spaced samples or lower levels for correlation of clusters.

A paleoenvironmental interpretation based on the four dominant acritarch genera (*Leiosphaeridia*, *Gloeocapsomorpha*, *Micrhystridium* and *Polygonium*) compliments the

interpretation based on the detailed stratigraphy and sedimentation of Quinn et al. (in prep.), supporting the notion that these sediments were deposited in an offshore shelf dominated environment. Differences in the acritarch assemblage zones are a reflection of sediment supply to the shelf as the sediments of the Winterhouse Formation, reflecting a change from a carbonate rich environment (the VA Zone), through a transition zone (the MA Zone), into a siliciclastic rich environment of the overlying Misty Point Formation (the PA Zone).

Microfossils and stratigraphic evidence suggest that the Winterhouse Formation was deposited in a developing foreland basin. It is therefore difficult to determine if the first occurrence of the species within this sequence represents a true first appearance, is a reflection of the changing environment, or is simply the result of the sampling interval. It is herein concluded that first appearances and abundance shifts are due to a mixture of all three factors. Until new species (fauna or flora) with more definitive ages are found, the age and correlation of the acritarch assemblages of the Winterhouse Formation will remain late Caradoc.

The interpretation of the paleoenvironments for the three assemblage zones have been made based on field observations and references to published literature. No detailed sedimentology or studies of the carbonate content from the various sampling intervals has been undertaken. As well there is no detailed isotopic work on the *Gloeocapsomorpha* ssp. and associated cryptospore assemblages.

An in-depth investigation of the acritarchs from the underlying Lourdes Formation could shed light on the biostratigraphy and age of this shallow water reef dominated assemblage, therein helping unravel the nature of the contact between the Lourdes and Winterhouse formations. If the VA Zone at the base of the Winterhouse Formation extends into the underlying Lourdes Formation, then the contact between these two formations may be considered conformable. Unfortunately, it is unlikely that information on acritarchs from the overlying Misty Point Formation will appear; this formation is coarse grained and oxidized to a bright red colour.

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## **APPENDIX**

Tables of raw data showing sampling  
intervals and species counts.

Shore Section	Base									
Sample Number	H-03-95	H-05-95	H-07-95	H-09-95	H-11-95	H-13-95	H-16-95	H-18-95	H-20-95	
Species	Depth in metres	0	3	13	25	35	41	50	60	70
<i>Actinotodissus crassus</i>										
<i>Actipilion druggii</i>					1					
<i>Ammonidium parvipinnatum</i>			1	3	1	23	7	15		
<i>Axisphaeridium tricolumnelar</i>						2	1			
<i>Bacisphaeridium</i> sp.										
<i>Baltisphaeridium accinctum</i>										
<i>B. aspersilumiferum</i>		5	1		1					1
<i>B. brevifilicum</i>			1		1					
<i>B. flosom</i>						3	5	15	12	
<i>B. nannum</i>	5		2	2						1
<i>Baltisphaeridium</i> sp.			1			1	1			
<i>Baltisphaerosum dispar</i>										
<i>Cheleutochroa diaphorosa</i>				3						
<i>Cheleutochroa</i> sp.				1						2
<i>Comasphaeridium lanugiferum</i>						2				
<i>C. varispinosum</i>						3	5	3	4	
<i>Comasphaeridium</i> sp. A			2	6		6	6	4	2	
<i>Comasphaeridium</i> sp. B							2	5	1	
? <i>Comasphaeridium</i> sp. C										
<i>Dicommopalla macadamii</i>										
<i>Excultibrachium concinnum</i>										
<i>Gloeocapsomorpha</i> sp.	61	15	11		14	25	9	22	23	
<i>Gorgonisphaeridium</i> sp. A										
<i>Gorgonisphaeridium</i> sp. B										
<i>Leiofusa fustiformis</i>										
<i>Lophosphaeridium aequicuspidatum</i>	1	3	1	1	1	1	1			
<i>L. edenense</i>						1				



Shore Section	Base									
Sample Number	H-03-95	H-05-95	H-07-95	H-09-95	H-11-95	H-13-95	H-16-95	H-18-95	H-20-95	
Species	Depth in metres	0	3	13	25	35	41	50	60	70
<i>L. papillatum</i>									1	
<i>L. papulatum</i>										
<i>Lunulida</i> sp. A										
<i>Lunulida</i> sp. B										
<i>Micrhystridium acuminosum</i>						1				1
<i>M. aremoricum</i>					1			6	3	5
<i>M. equispinosum</i>			4	1	8	5		15	11	6
<i>M. fragile</i>	1	2	4	3	36	6	21	33	14	
<i>M. shinetonense</i>	1	23	4	12	19	3	24	21	21	
<i>Micrhystridium</i> sp. A	8		7			6				
<i>Micrhystridium</i> sp. B					1		1	7		
<i>Micrhystridium</i> sp. C		9	3	8		6	15	10	13	
<i>Moyeria cabottii</i>						1				
<i>Multiplicisphaeridium irregulare</i>		3	5	5	2	1	4	5	2	
<i>Multiplicisphaeridium</i> sp. A	10	4	21							1
<i>Multiplicisphaeridium</i> sp. B			1					1		
<i>M. martae</i>					1	2				3
<i>Navifusa similis</i>				1	1					2
<i>Ordovicidium groetlingboensis</i>		1	1		1	1		1	1	
<i>O. heteromorphicum</i>			1					3		
<i>Ordovicidium</i> sp.					1			1	2	
<i>Petaloferridium stigi</i>										
<i>Petaloferridium</i> sp.						1				
<i>Poikilofusa</i> sp. cf <i>P. spinata</i>										
<i>Polyancistrodorus columbariferus</i>		4			1					1
<i>Polygonium connectum</i>										

Shore Section	Base								
Sample Number	H-03-95	H-05-95	H-07-95	H-09-95	H-11-95	H-13-95	H-16-95	H-18-95	H-20-95
Species      Depth in metres	0	3	13	25	35	41	50	60	70
<i>P. gracile</i>	2	8	2	2	5	2		4	
<i>P. tenuispinosum</i>									
<i>Polygonium sp. A</i>									
<i>Polygonium sp. B</i>					1		1		
<i>Polygonium sp. C</i>					8	1		1	
<i>Pterospermella sp.</i>									
<i>Rhachosoarium lappaceum</i>									
<i>Uranidium semicalvum</i>				1					1
<i>Veryhachium downiei</i>								1	
<i>V. oklahomense</i>	2	2			1	1	4	1	
<i>V. rhomboidium</i>	2							1	
<i>V. trispinosum</i>		2		51	2		3	1	21
<i>V. valiente</i>		1		1	2				5
<i>Villosacapsula entrichos</i>		1			1	1			
<i>V. irroratum</i>							2		
<i>V. setosapellicula</i>	2	30	3		1	3	4	3	
<i>Cryptospore sp. A</i>									
<i>Cryptospore sp. B</i>									
<i>Cymatiosphaeria sp. A</i>									
<i>Cymatiosphaeria sp. B</i>									
<i>Leiosphaeridia sp.</i>	71	55	91	38	62	86	68	74	109
<b>Total Specimen Counts per sample</b>	<b>166</b>	<b>172</b>	<b>164</b>	<b>148</b>	<b>173</b>	<b>185</b>	<b>205</b>	<b>247</b>	<b>254</b>
Lycopodium counts per sample	160	124	154	82	43	202	211	222	168

Shore Section										
Sample Number		H-22-95	H-25-95	H-28-95	H-30-95	H-32-95	H-34-95	H-36-95	H-38-95	H-42-95
Species	Depth in metres	80	95	102	110	120	130	140	150	161.00
<i>Actinotodissus crassus</i>								4	1	
<i>Actipilion druggii</i>										
<i>Ammonidium parvipinnatum</i>				3	4	1	3	3	2	1
<i>Axisphaeridium tricornular</i>			1							
<i>Bacisphaeridium</i> sp.								1		
<i>Baltisphaeridium accinctum</i>										
<i>B. aspersilumiferum</i>										2
<i>B. brevifilicum</i>			1	1						
<i>B. filusum</i>		9	2	2	6		12	9	23	5
<i>B. nannum</i>				1			3	2	1	
<i>Baltisphaeridium</i> sp.				1					1	
<i>Baltisphaerosum dispar</i>									1	
<i>Cheleutochroa diaphorosa</i>										
<i>Cheleutochroa</i> sp.										
<i>Comasphaeridium lanugiferum</i>										
<i>C. varispinosum</i>		3	5		2	2	3	6	1	1
<i>Comasphaeridium</i> sp. A		1	11	10	11	7	11	5	9	7
<i>Comasphaeridium</i> sp. B		1	12	6	5	7	6	2	1	3
? <i>Comasphaeridium</i> sp. C						1	3			
<i>Dicommopalla macadamii</i>										
<i>Excultibrachium concinnum</i>			2	1					1	
<i>Gloeocapsomorpha</i> sp.		23	24	25	38	12	23	11	7	7
<i>Gorgonisphaeridium</i> sp. A										
<i>Gorgonisphaeridium</i> sp. B			1							
<i>Leiofusa fusiformis</i>										
<i>Lophosphaeridium aequicuspidatum</i>		1	1	1	2			5	1	4
<i>L. edenense</i>					2		2	1		

Shore Section										
Sample Number		H-22-95	H-25-95	H-28-95	H-30-95	H-32-95	H-34-95	H-36-95	H-38-95	H-42-95
Species	Depth in metres	80	95	102	110	120	130	140	150	161.00
<i>L. papillatum</i>										1
<i>L. papulatum</i>										1
<i>Lunulida sp. A</i>										
<i>Lunulida sp. B</i>										
<i>Micrhystridium acuminosum</i>		1					2	1		1
<i>M. aremoricum</i>		4	1	2	6	1	7			4
<i>M. equispinosum</i>		2	7	2	4	3	6	3	5	7
<i>M. fragile</i>		11	6	15	10	3	3	11	14	13
<i>M. shinetonense</i>		25	13	8	23	17	16	10	4	33
<i>Micrhystridium sp. A</i>										
<i>Micrhystridium sp. B</i>			1	1	1		2		1	1
<i>Micrhystridium sp. C</i>		5	4	2	5	4	4	2	11	1
<i>Moyeria cabottii</i>							1			
<i>Multiplicisphaeridium irregulare</i>		1				1	1		1	
<i>Multiplicisphaeridium sp. A</i>		8	5	6		5	8	4	2	1
<i>Multiplicisphaeridium sp. B</i>		1	1		4	2		2		
<i>M. mariae</i>									1	
<i>Navifusa similis</i>				1						
<i>Ordovicidium groetlingboensis</i>		1			2					
<i>O. heteromorphicum</i>										
<i>Ordovicidium sp.</i>									1	
<i>Petalosferidium stigii</i>										
<i>Petalosferidium sp.</i>										
<i>Poikilofusa sp. cf P. spinata</i>										
<i>Polyancistrodorus columbariferus</i>			1			1				
<i>Polygonium connectum</i>			2	1			3	7		

Shore Section										
Sample Number		H-22-95	H-25-95	H-28-95	H-30-95	H-32-95	H-34-95	H-36-95	H-38-95	H-42-95
Species	Depth in metres	80	95	102	110	120	130	140	150	161.00
<i>P. gracile</i>		1	1	2	2	2	4	3	2	
<i>P. tenuispinosum</i>										
<i>Polygonium sp. A</i>										
<i>Polygonium sp. B</i>								1		
<i>Polygonium sp. C</i>				1	2	1				1
<i>Pterospermella sp.</i>										
<i>Rhachosoarium lappaceum</i>										
<i>Uranidium semicalvum</i>			1	2						
<i>Veryhachium downiei</i>										
<i>V. oklahomense</i>		1								2
<i>V. rhomboidium</i>						1			1	
<i>V. trispinosum</i>		10	3	2	2	5	2		5	3
<i>V. valiente</i>		2	5	2	5		1	2	1	3
<i>Villosacapsula entrichos</i>										
<i>V. irroratum</i>										
<i>V. setosapellicula</i>		13		9	2		7	29	3	1
<i>Cryptospore sp. A</i>										
<i>Cryptospore sp. B</i>										
<i>Cymatiosphaeria sp. A</i>										
<i>Cymatiosphaeria sp. B</i>										
<i>Leiosphaeridia sp.</i>		78	100	106	111	132	188	132	116	62
Total Specimen Counts per sample		202	211	213	249	208	321	256	217	165
Lycopodium counts per sample		158	215	128	189	54	155	136	200	41

Shore Section										
Sample Number		H-44-95	H-69-95	H-71-95	H-72b-95	H-74-95	H-76-95	H-78-95	H-81-95	H-82-95
Species	Depth in metres	170.00	200.00	210.00	220.00	230.00	240.00	250.00	270.00	275.00
<i>Actinotodissus crassus</i>									4	
<i>Actipilion druggii</i>									1	
<i>Ammonidium parvipinnatum</i>			2							
<i>Axisphaeridium tricornular</i>							1		1	
<i>Bacisphaeridium</i> sp.										
<i>Baltisphaeridium accinctum</i>				1						
<i>B. aspersilumiferum</i>					2	1	1		2	
<i>B. brevifilicum</i>					1					1
<i>B. filiosum</i>		2		6	15	9	9	11	33	3
<i>B. nanum</i>										2
<i>Baltisphaeridium</i> sp.				2		1	1		4	2
<i>Baltisphaerosum dispar</i>					1					1
<i>Cheleutochroa diaphorosa</i>										
<i>Cheleutochroa</i> sp.									3	
<i>Comasphaeridium lanugiferum</i>										
<i>C. varispinosum</i>		1	4	4			18	7	6	
<i>Comasphaeridium</i> sp. A		7	2	9	7	1	4	3	5	23
<i>Comasphaeridium</i> sp. B		1	2	2	2		1			6
? <i>Comasphaeridium</i> sp. C										
<i>Dicommopalla macadamii</i>										
<i>Excultibrachium concinnum</i>					1					
<i>Gloeocapsomorpha</i> sp.		1	8	4	43	1	1	5	2	6
<i>Gorgonisphaeridium</i> sp. A					3					
<i>Gorgonisphaeridium</i> sp. B										
<i>Leiofusa fusiformis</i>										
<i>Lophosphaeridium aequicuspdatum</i>			1	2	1		1		8	
<i>L. edenense</i>										

Shore Section										
Sample Number		H-44-95	H-69-95	H-71-95	H-72b-95	H-74-95	H-76-95	H-78-95	H-81-95	H-82-95
Species	Depth in metres	170.00	200.00	210.00	220.00	230.00	240.00	250.00	270.00	275.00
<i>L. papillatum</i>										
<i>L. papulatum</i>										
<i>Lunulida sp. A</i>										
<i>Lunulida sp. B</i>										
<i>Micrhystridium acuminosum</i>							1	5		
<i>M. aremoricatum</i>			2	3	3		2	2		4
<i>M. equispinosum</i>			5	42	7	33	29	24	10	6
<i>M. fragile</i>			3		8	18	10	4	9	10
<i>M. shinetonense</i>		3	23	7	11	13	4	5	19	18
<i>Micrhystridium sp. A</i>										
<i>Micrhystridium sp. B</i>							1	2	1	
<i>Micrhystridium sp. C</i>			7	5	7	10	9	6	80	
<i>Moyeria cabottii</i>		2	1	1					1	
<i>Multiplicisphaeridium irregulare</i>					2				8	1
<i>Multiplicisphaeridium sp. A</i>			3	2	2	15	7		2	
<i>Multiplicisphaeridium sp. B</i>			3		1	7		3	12	6
<i>M. martaie</i>								1		
<i>Navifusa similis</i>							2		1	1
<i>Ordoviciidium groetlingboensis</i>		3	2	1	1	1	1		1	1
<i>O. heteromorphicum</i>										
<i>Ordoviciidium sp.</i>					1					
<i>Petalosferidium stigii</i>										1
<i>Petalosferidium sp.</i>										
<i>Poikilofusa sp. cf P. spinata</i>										
<i>Polyancistrodorus columbariferus</i>					1				1	1
<i>Polygonium connectum</i>						5	3	3	4	7

Shore Section										
Sample Number		H-44-95	H-69-95	H-71-95	H-72b-95	H-74-95	H-76-95	H-78-95	H-81-95	H-82-95
Species	Depth in metres	170.00	200.00	210.00	220.00	230.00	240.00	250.00	270.00	275.00
<i>P. gracile</i>		2	4			3	5		6	5
<i>P. tenuispinosum</i>										
<i>Polygonium sp. A</i>								1	3	
<i>Polygonium sp. B</i>					1				1	
<i>Polygonium sp. C</i>									1	1
<i>Pterospermella sp.</i>										
<i>Rhachosoarium lappaceum</i>							1			
<i>Uranidium semicalvum</i>										
<i>Veryhachium downiei</i>		1				1				
<i>V. oklahomense</i>		2	12	5	2	7	10	3		2
<i>V. rhomboidium</i>								4	8	6
<i>V. trispinosum</i>		13	1			3	1	1	1	2
<i>V. valiente</i>			2	3	1	1	11	2	5	8
<i>Villosacapsula entrichos</i>										
<i>V. irroratum</i>										
<i>V. setosapellicula</i>										
<i>Cryptospore sp. A</i>										
<i>Cryptospore sp. B</i>										
<i>Cymatiosphaeria sp. A</i>										
<i>Cymatiosphaeria sp. B</i>								1		
<i>Leiosphaeridia sp.</i>		90	109	132	104	107	151	104	90	99
Total Specimen Counts per sample		128	196	231	228	237	285	197	333	223
Lycopodium counts per sample		90	103	187	130	217	65	166	100	210



Shore Section						Top		
Sample Number	H-83-95	H-85-95	H-87-95	H-88b-95	H-89-95	H-90-95		
Species      Depth in metres	280.00	290.00	300.00	320.00	330.00	350.00		
<i>Actinotodissus crassus</i>						3		
<i>Actipilion druggii</i>								
<i>Ammonidium parvipinnatum</i>						1		
<i>Axisphaeridium tricolumnelar</i>	1		2	2		3		
<i>Bacisphaeridium</i> sp.								
<i>Baltisphaeridium accinctum</i>				1				
<i>B. aspersilumiferum</i>								
<i>B. brevifilicum</i>	1	1	1					
<i>B. filosum</i>	2	3	5	15	7	9		
<i>B. nannum</i>								
<i>Baltisphaeridium</i> sp.	1		1	1	1	1		
<i>Baltisphaerosum dispar</i>				1		1		
<i>Cheleutochroa diaphorosa</i>								
<i>Cheleutochroa</i> sp.						1		
<i>Comasphaeridium lanugiferum</i>								
<i>C. varispinosum</i>	5	2	5	5	3	1		
<i>Comasphaeridium</i> sp. A		1	5	2	3			
<i>Comasphaeridium</i> sp. B	2	2	1	1	1			
? <i>Comasphaeridium</i> sp. C								
<i>Dicommopalla macadamii</i>						1		
<i>Excultibrachium concinnum</i>								
<i>Gloeocapsomorpha</i> sp.	3	2	4	3	6	2		
<i>Gorgonisphaeridium</i> sp. A								
<i>Gorgonisphaeridium</i> sp. B								
<i>Leiofusa fusiformis</i>								
<i>Lophosphaeridium aequicuspidatum</i>	2							
<i>L. edenense</i>				1	4	1		

Shore Section							Top		
Sample Number		H-83-95	H-85-95	H-87-95	H-88b-95	H-89-95	H-90-95		
Species	Depth in metres	280.00	290.00	300.00	320.00	330.00	350.00		
<i>L. papillatum</i>									
<i>L. papulatum</i>							1		
<i>Lunulida sp. A</i>									
<i>Lunulida sp. B</i>									
<i>Micrhystridium acuminosum</i>						2	2		
<i>M. aremoricum</i>			5	1	1	7	18		
<i>M. equispinosum</i>		4	12	3	5		4		
<i>M. fragile</i>		7	5	6			3		
<i>M. shinetonense</i>		30	27	4	3	19	17		
<i>Micrhystridium sp. A</i>									
<i>Micrhystridium sp. B</i>			1	5	2				
<i>Micrhystridium sp. C</i>		25	49	19	16	13	17		
<i>Moyeria cabottii</i>							1		
<i>Multiplicisphaeridium irregulare</i>		1	5	5	2	1	5		
<i>Multiplicisphaeridium sp. A</i>		11	8	5	4	4	11		
<i>Multiplicisphaeridium sp. B</i>		1		4		1	1		
<i>M. martae</i>			4		9	3	5		
<i>Navifusa similis</i>				2		1	1		
<i>Ordovicidium groetlingboensis</i>				2		1	2		
<i>O. heteromorphicum</i>							4		
<i>Ordovicidium sp.</i>									
<i>Petalosphaeridium stigmii</i>									
<i>Petalosphaeridium sp.</i>									
<i>Poikilofusa sp. cf P. spinata</i>									
<i>Polyancistrodorus columbariferus</i>						1	1		
<i>Polygonium connectum</i>		2		1	2				

Shore Section							Top	
Sample Number		H-83-95	H-85-95	H-87-95	H-88b-95	H-89-95	H-90-95	
Species	Depth in metres	280.00	290.00	300.00	320.00	330.00	350.00	
<i>P. gracile</i>		4	4	1	2		2	
<i>P. tenuispinosum</i>						1	1	
<i>Polygonium sp. A</i>		1	1					
<i>Polygonium sp. B</i>								
<i>Polygonium sp. C</i>				11	7	5	13	
<i>Pterospermella sp.</i>								
<i>Rhachosoarium lappaceum</i>							1	
<i>Uranidium semicalvum</i>			1					
<i>Veryhachium downiei</i>								
<i>V. oklahomense</i>		8	5		1		1	
<i>V. rhomboidium</i>			1	2	4	1	1	
<i>V. trispinosum</i>			1		1			
<i>V. valiente</i>				2	1	1	1	
<i>Villosacapsula entrichos</i>							1	
<i>V. irroratum</i>								
<i>V. setosapellicula</i>								
<i>Cryptospore sp. A</i>								
<i>Cryptospore sp. B</i>								
<i>Cymatiosphaeria sp. A</i>								
<i>Cymatiosphaeria sp. B</i>								
<i>Leiosphaeridia sp.</i>		55	102	86	66	75	75	
Total Specimen Counts per sample		166	242	183	158	161	213	
Lycopodium counts per sample		111	201	100	307	203	203	

River Section	Base						Top
Sample Number	H-64-95	H-63-95	H-62-95	H-61-95	H-58-95	H-56-95	H-54-95
Species	Depth in metres	91.00	85.00	50.00	36.00	20.00	10.00 0
<i>Actinotodissus crassus</i>				1	1		
<i>Actipilion druggii</i>							
<i>Ammonidium parvipinnatum</i>			2				
<i>Axisphaeridium tricornelae</i>	1						
<i>Bacisphaeridium sp.</i>							
<i>Baltisphaeridium accinctum</i>	4		3			1	1
<i>B. aspersilumiferum</i>	1		1		2		1
<i>B. brevifilicum</i>					1		
<i>B. filiosum</i>	8		2	1		1	
<i>B. nannum</i>					8		
<i>Baltisphaeridium sp.</i>						1	
<i>Baltisphaerosum dispar</i>							
<i>Cheleutochroa diaphorosa</i>	1						
<i>Cheleutochroa sp.</i>	1						
<i>Comasphaeridium lanugiferum</i>						1	6
<i>C. varispinosum</i>	2		3	1		2	
<i>Comasphaeridium sp. A</i>	32		4			5	
<i>Comasphaeridium sp. B</i>	5		1				
? <i>Comasphaeridium sp. C</i>	1					1	
<i>Dicommopalla macadamii</i>				1			
<i>Excultibrachium concinnum</i>							
<i>Gloeocapsomorpha sp.</i>	9	2	22	12	1	5	18
<i>Gorgonisphaeridium sp. A</i>	8					1	
<i>Gorgonisphaeridium sp. B</i>	5				1	4	
<i>Leiofusa fusiformis</i>				1			
<i>Lophosphaeridium aequicuspdatum</i>	5		3	14	1	2	
<i>L. edenense</i>	8		2	1			1

River Section	Base						Top	
Sample Number	H-64-95	H-63-95	H-62-95	H-61-95	H-58-95	H-56-95	H-54-95	
Species	Depth in metres	91.00	85.00	50.00	36.00	20.00	10.00	0
<i>L. papillatum</i>	3		2	1		2	3	
<i>L. papulatum</i>	1					2	2	
<i>Lunulida sp. A</i>								
<i>Lunulida sp. B</i>								
<i>Micrhystridium acuminosum</i>								
<i>M. aremoricanum</i>				1				
<i>M. equispinosum</i>	18		5	18		38		
<i>M. fragile</i>	6	1	3	1		1	1	
<i>M. shinetonense</i>	12	9	7	16		2	1	
<i>Micrhystridium sp. A</i>								
<i>Micrhystridium sp. B</i>	2		1			1		
<i>Micrhystridium sp. C</i>	12	1	30	8	1	4	5	
<i>Moyeria cabottii</i>	3		1		8	19	1	
<i>Multiplicisphaeridium irregulare</i>	9		1			1	1	
<i>Multiplicasphaeridium sp. A</i>	12		10	3	4		6	
<i>Multiplicasphaeridium sp. B</i>			1					
<i>M. martae</i>								
<i>Navifusa similis</i>	5			1		1		
<i>Ordovicidium groetlingboensis</i>	1				2		2	
<i>O. heteromorphicum</i>	1							
<i>Ordovicidium sp.</i>								
<i>Petaloferidium stigii</i>					3			
<i>Petaloferidium sp.</i>	1			1	1	1	1	
<i>Poikilofusa sp. cf P. spinata</i>	1		1			1	1	
<i>Polyancistrodorus columbariferus</i>	1	2	1				1	
<i>Polygonium connectum</i>	2		1		1	1		

River Section	Base							Top
Sample Number	H-64-95	H-63-95	H-62-95	H-61-95	H-58-95	H-56-95	H-54-95	
Species	Depth in metres	91.00	85.00	50.00	36.00	20.00	10.00	0
<i>P. gracile</i>	50			37	3	4	9	9
<i>P. tenuispinosum</i>				2		2	1	
<i>Polygonium sp. A</i>	1			6	2	2	1	1
<i>Polygonium sp. B</i>	1							
<i>Polygonium sp. C</i>	1							
<i>Pterospermella sp.</i>				1			1	
<i>Rhachosoarium lappaceum</i>	1						1	1
<i>Uranidium semicalvum</i>	1			1	1	1		2
<i>Veryhachium downiei</i>								
<i>V. oklahomense</i>	3			9			2	
<i>V. rhomboidium</i>						2	3	3
<i>V. trispinosum</i>	2		1				1	1
<i>V. valiente</i>	10		1	12	14	1	4	2
<i>Villosacapsula entrichos</i>	5				1		1	8
<i>V. irroratum</i>	1							
<i>V. setosapellicula</i>					1			
<i>Cryptospore sp. A</i>						1		1
<i>Cryptospore sp. B</i>	1			1		1	9	1
<i>Cymatiosphaeria sp. A</i>	1					2		
<i>Cymatiosphaeria sp. B</i>								
<i>Leiosphaeridia sp.</i>	181	15	156	75	73	124		114
Total Specimen Counts per sample	440	32	332	179	124	255	195	
Lycopodium counts per sample	334	262	200	390	200	100	144	

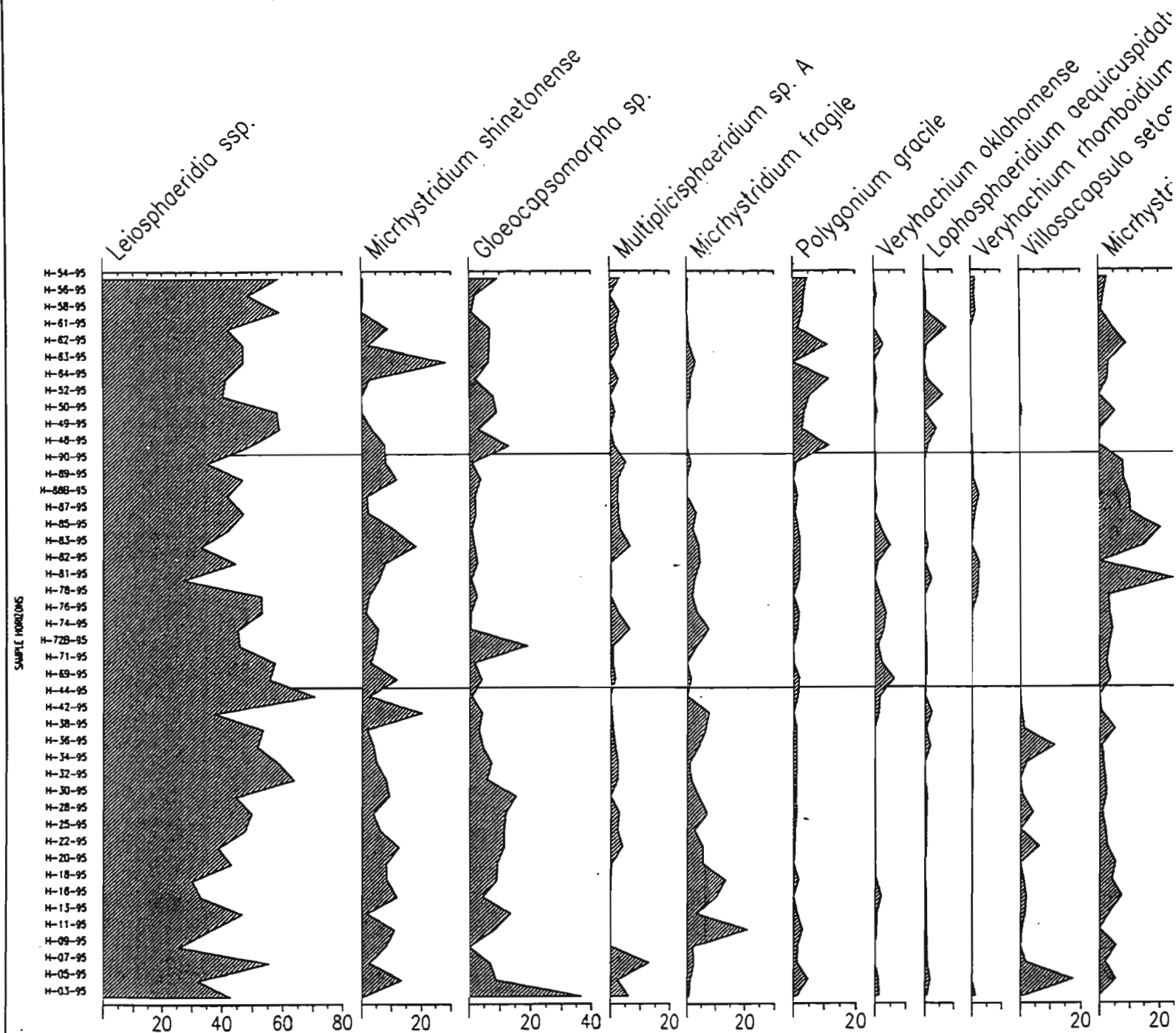
Cliff Section	Base			Top	
Sample Number	H-48-95	H-49-95	H-50-95	H-52-95	
Species	Depth in metres	0	5.00	10.00	20.00
<i>Actinotodissus crassus</i>					
<i>Actipilion druggii</i>					
<i>Ammonidium parvipinnatum</i>					
<i>Axisphaeridium tricornular</i>		1	2		
<i>Bactisphaeridium</i> sp.					
<i>Baltisphaeridium accinctum</i>			2		1
<i>B. aspersilumiferum</i>		1	4	1	1
<i>B. microspinosum</i>					
<i>B. filiosum</i>			1		
<i>B. nannum</i>					
<i>Baltisphaeridium</i> sp.					
<i>Baltisphaerosum dispar</i>					
<i>Cheleutochroa diaphorosa</i>					
<i>Cheleutochroa</i> sp.					
<i>Comasphaeridium lanugiferum</i>					
<i>C. varispinosum</i>					
<i>Comasphaeridium</i> sp. A			2		
<i>Comasphaeridium</i> sp. B					
? <i>Comasphaeridium</i> sp. C				1	
<i>Dicommopalla macadamii</i>					
<i>Excultibrachium concinnum</i>					
<i>Gloeocapsomorpha</i> sp.		19	6	12	6
<i>Gorgonisphaeridium</i> sp. A					
<i>Gorgonisphaeridium</i> sp. B					
<i>Leiofusa fusiformis</i>					
<i>Lophosphaeridium aequicuspdatum</i>		2	8		5
<i>L. edenense</i>		2	2	7	3

Cliff Section	Base			Top	
Sample Number	H-48-95	H-49-95	H-50-95	H-52-95	
Species	Depth in metres	0	5.00	10.00	20.00
<i>L. papillatum</i>			2		2
<i>L. papulatum</i>	1	1			
<i>Lunulida sp. A</i>					1
<i>Lunulida sp. B</i>		1			
<i>Micrhystridium acuminosum</i>					
<i>M. aremoricanum</i>					
<i>M. equispinosum</i>	1	13	1		
<i>M. fragile</i>					1
<i>M. shinetonense</i>	12	7			
<i>Micrhystridium sp. A</i>					
<i>Micrhystridium sp. B</i>		3			1
<i>Micrhystridium sp. C</i>		1	7		
<i>Moyeria cabottii</i>	4	8	4		2
<i>Multiplicisphaeridium irregulare</i>		1	1		
<i>Multiplicasphaeridium sp. A</i>	2		2		
<i>Multiplicasphaeridium sp. B</i>					1
<i>M. martaie</i>					
<i>Navifusa similis</i>		1			1
<i>Ordoviciidium groetlingboenis</i>			1		1
<i>O. heteromorphicum</i>					
<i>Ordoviciidium sp.</i>					
<i>Petalosferidium stigii</i>			1		
<i>Petalosferidium sp.</i>					1
<i>Poikilofusa sp. cf P. spinata</i>		1			
<i>Polyancistrodorus columbariferus</i>		1	1		1
<i>Polygonium connectum</i>	1	2	1		9

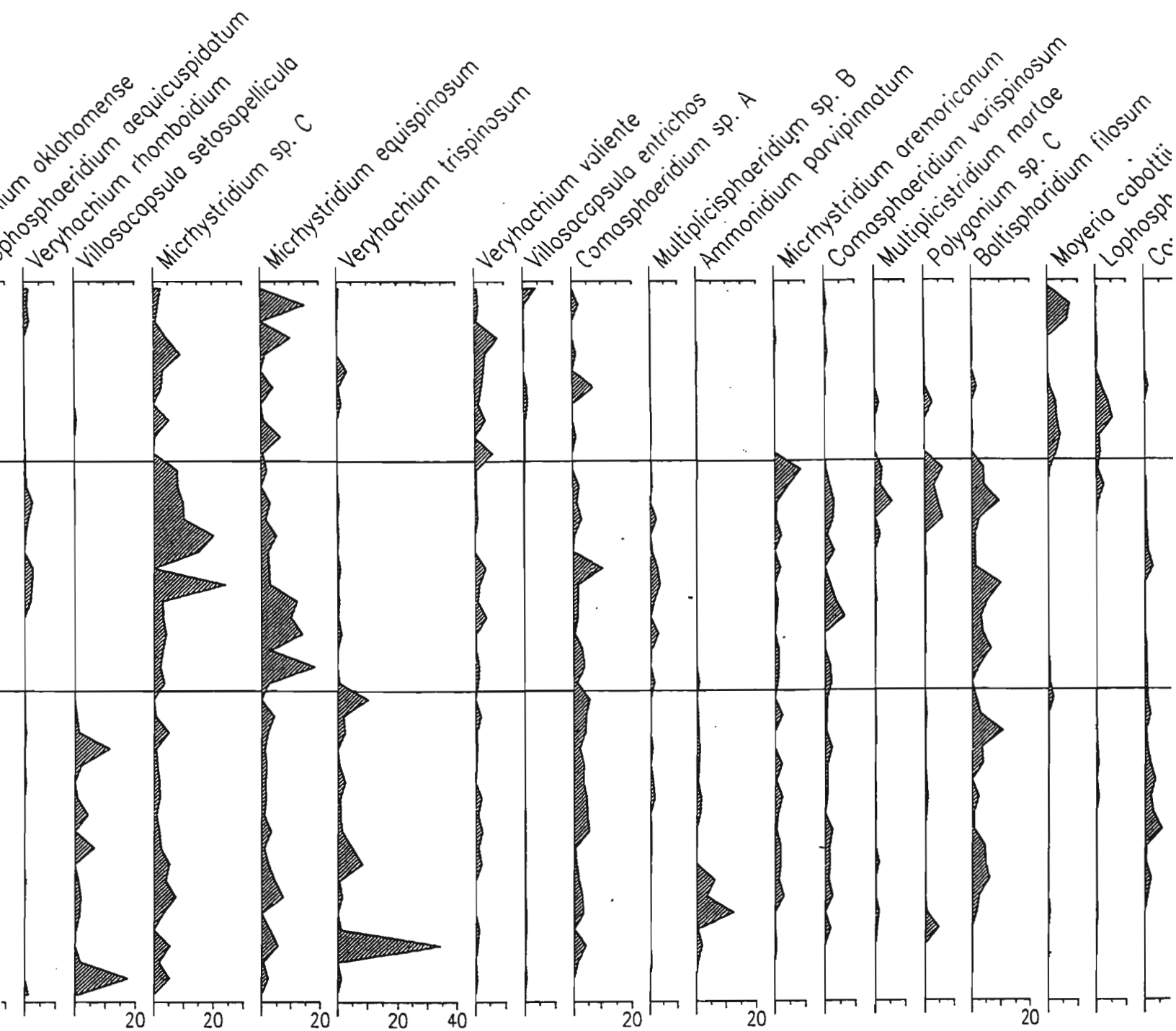


Cliff Section	Base			Top	
Sample Number	H-48-95	H-49-95	H-50-95	H-52-95	
Species	Depth in metres	0	5.00	10.00	20.00
<i>P. gracile</i>	17	6	5	4	
<i>P. tenuispinosum</i>	1				
<i>Polygonium sp. A</i>		1	1	1	
<i>Polygonium sp. B</i>					
<i>Polygonium sp. C</i>					2
<i>Pterospermella sp.</i>					
<i>Rhachosoarium lappaceum</i>					
<i>Uranidium semicalvum</i>					
<i>Verhachium downiei</i>					
<i>V. oklahomense</i>				1	
<i>V. rhomboidium</i>	1				
<i>V. trispinosum</i>					1
<i>V. valiente</i>	9			5	1
<i>Villosacapsula entrichos</i>	1	1	1	1	1
<i>V. irroratum</i>					
<i>V. setosapellicula</i>				1	
<i>Cryptospore sp. A</i>					
<i>Cryptospore sp. B</i>	1	4	3		
<i>Cymatiosphaeria sp. A</i>		1			1
<i>Cymatiosphaeria sp. B</i>				1	
<i>Letosphaeridia sp.</i>	73	117	79	31	
Total Specimen Counts per sample	149	199	137	79	
Lycopodium counts per sample	320	308	312	303	

Chart 1: Three assemblage zones of the Winterhouse Formation, base on the total sum of nine squares.









*eridium* sp. B  
*idium parvipinnatum*  
*Michystridium aremaricanum*  
*Comasphaeridium varispinosum*  
*Multiplicistridium martae*  
*Polygonium* sp. C  
*Baltisphaeridium filosum*  
*Moyeria cabottii*  
*Lophosphaeridium edenense*  
*Comasphaeridium* sp. B  
*Polygonium connectum*  
*Baltisphaerosum dispar*  
*Polygonium* sp. A  
*Petaloferidium stiglii*  
*Cryptospore* sp. B\*

ZONES

CONISS

PA

MA

VA

Total sum of squares

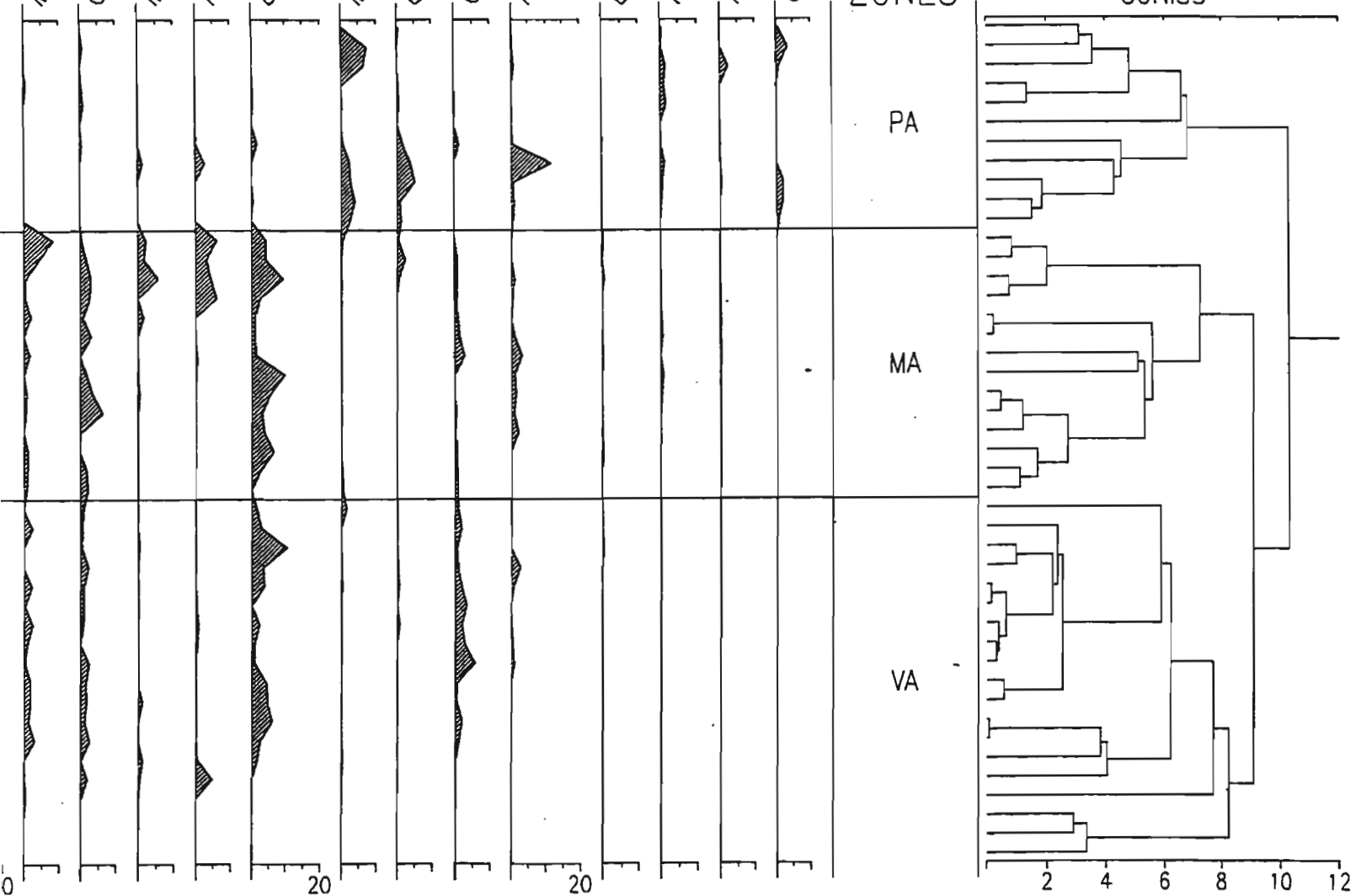
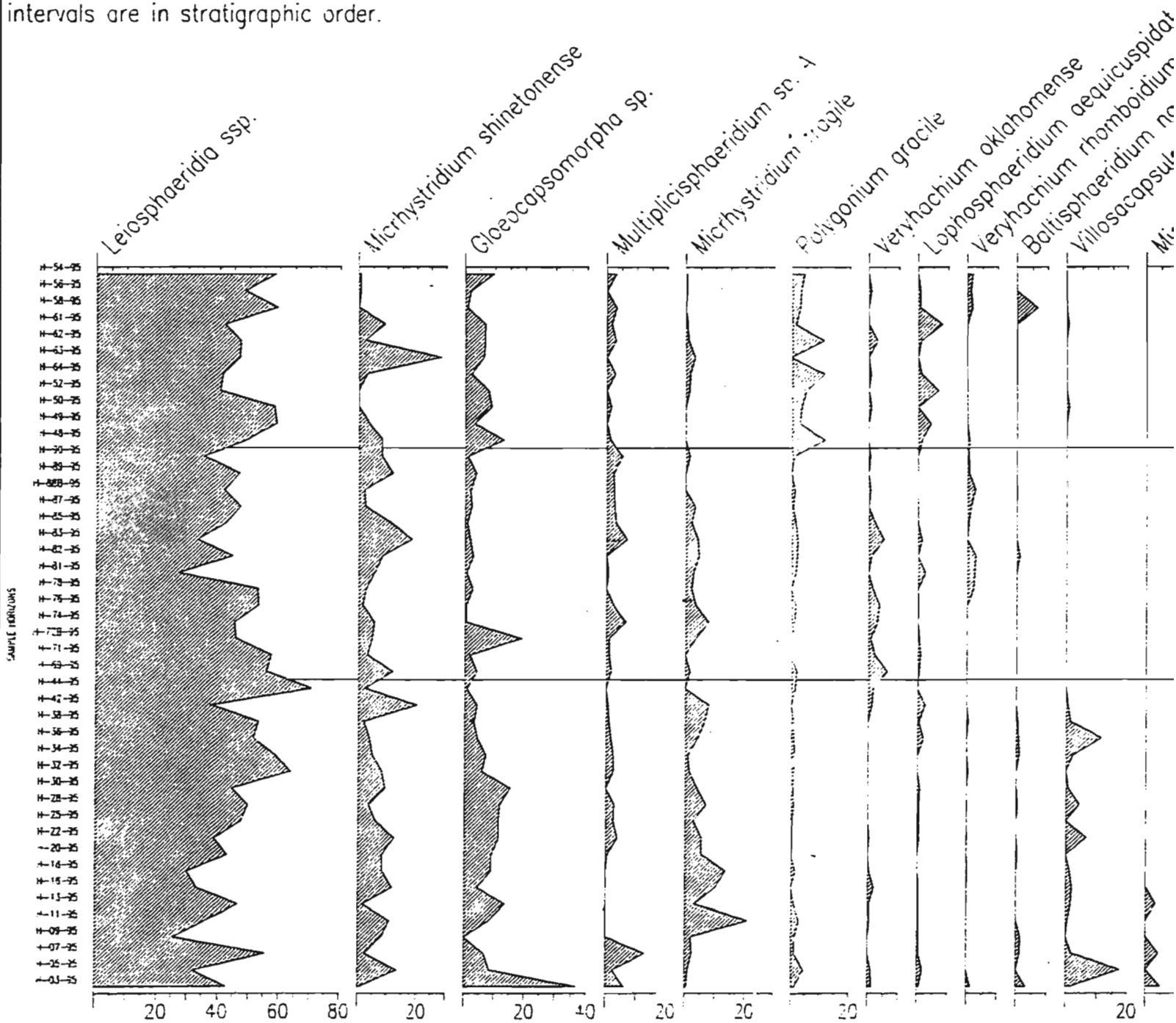


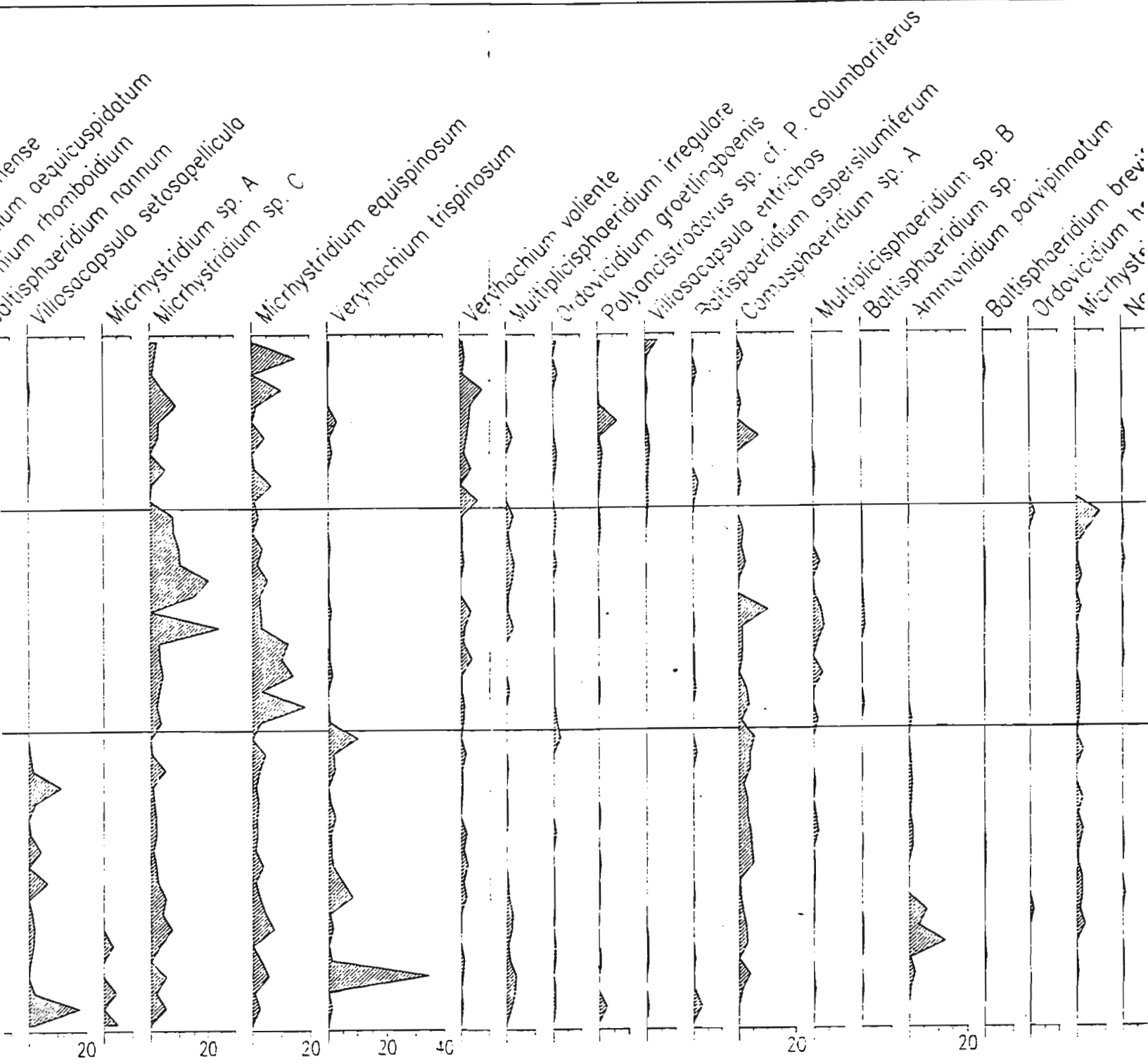


Chart 2. Range and percent relative abundance of palynomorphs present in the Winterhouse Formation, ordered by first appearance. Sample intervals are in stratigraphic order.

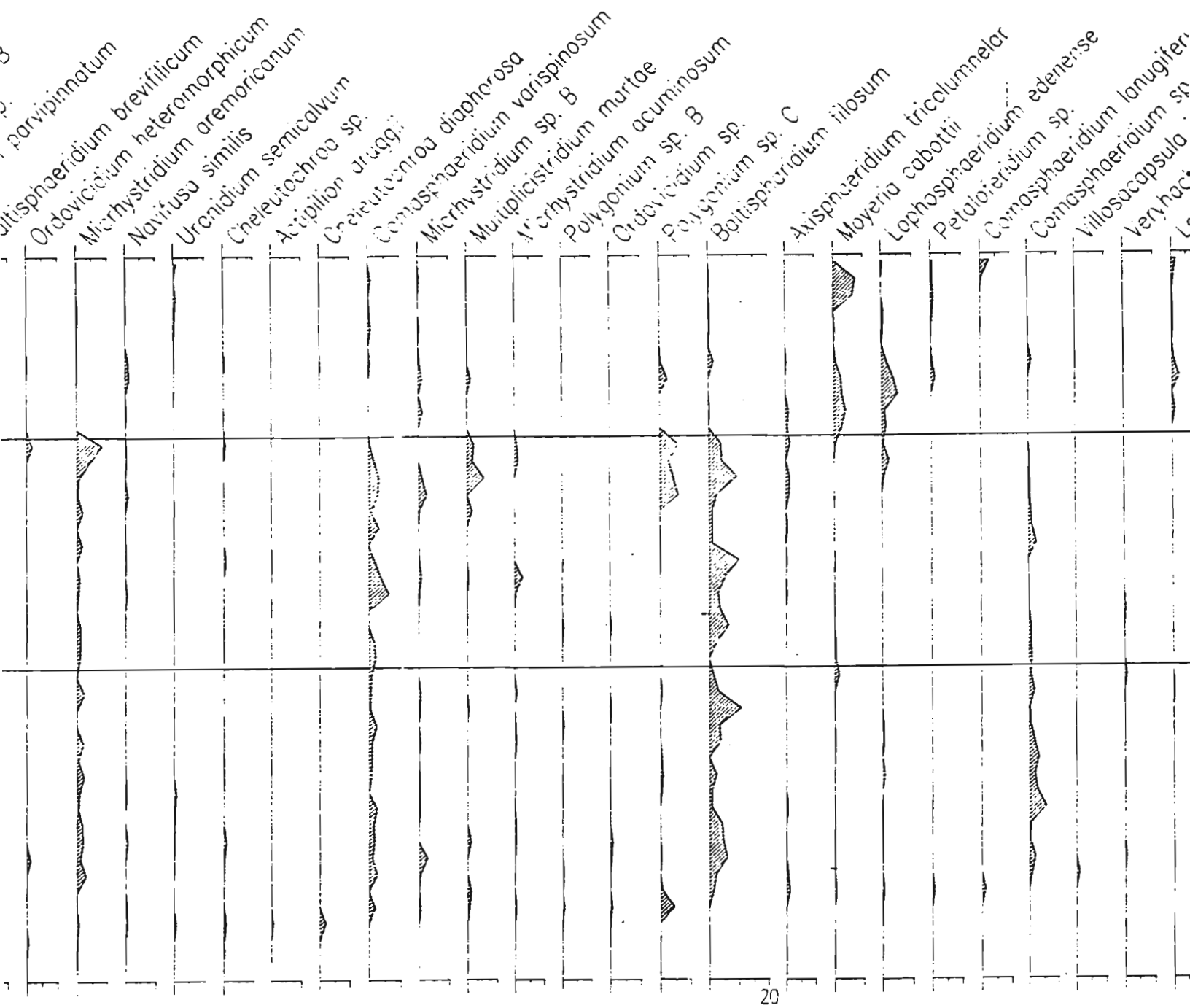














edense  
 n. sp.  
 Comasphaeridium lanugiferum  
 Comasphaeridium sp. B  
 Villosacapsula irroratum  
 Verhucium downiei  
 Lophosphaeridium popillatum  
 Polygonium connectum  
 Gorgonispheeridium sp. B  
 Excultibrachium concinnum  
 ? Comasphaeridium sp. C  
 Bacisphaeridium sp. C  
 Actinotadissus sp.  
 Baltispheerosum crassus  
 Lophosphaeridium dispar  
 Baltispheeridium populatum  
 Gorgonispheeridium accinctum  
 Pinachosarium sp. A  
 Polygonium sp. A  
 Cymatiosphaeria lappaceum  
 Petalotripteridium sp. B  
 Polygonium stiglii  
 Dicommeopalla macadamii  
 Cryptospere sp. B  
 Mikilofusa sp. cf. P  
 Cymatiosphaeria  
 Lundia



*populatum*  
*um accinctum*  
*enischaeeridium sp. A*  
*Anachosarium lappaceum*  
*Polygonium sp. A*  
*Cymatiosphaeria sp. B*  
*Pectoteteridium stiglii*  
*Polygonium tenuispinosum*  
*Diconimicaria macadamii*  
*Cryptospore sp. B*  
*Polikilofusa sp. cf. P. spinata*  
*Cymatiosphaeria sp. A*  
*Lunulida sp. B*  
*Lunulida sp. A*  
*Sterospermella sp.*  
*Leclusa fusiformis*  
*Cryptospore sp. A*

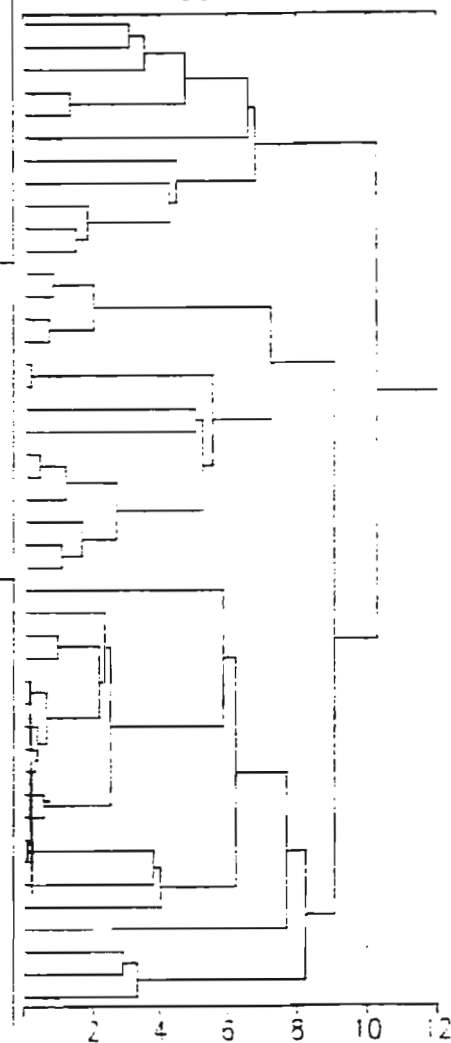
ZONES

PA

MA

VA

CONISS



Total sum of squares









